Modelling Ice Shelf/Ocean Interaction

Ben Galton-Fenzi

bkgalton@utas.edu.au

Antarctic Climate and Ecosystems CRC

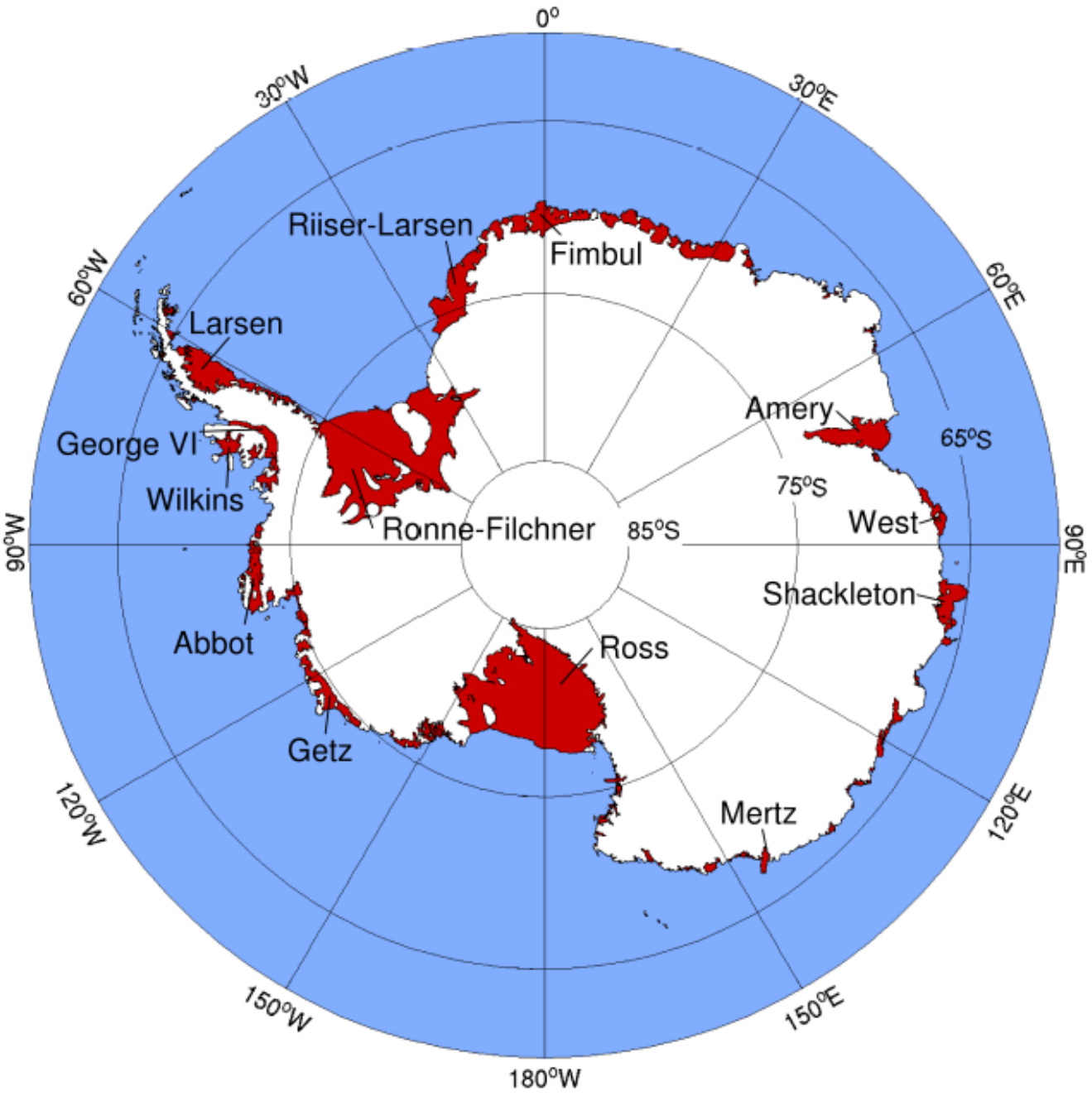
Hobart, Tasmania, Australia

IPCC Fourth Assesment Resport Summary for Policymakers (2007)

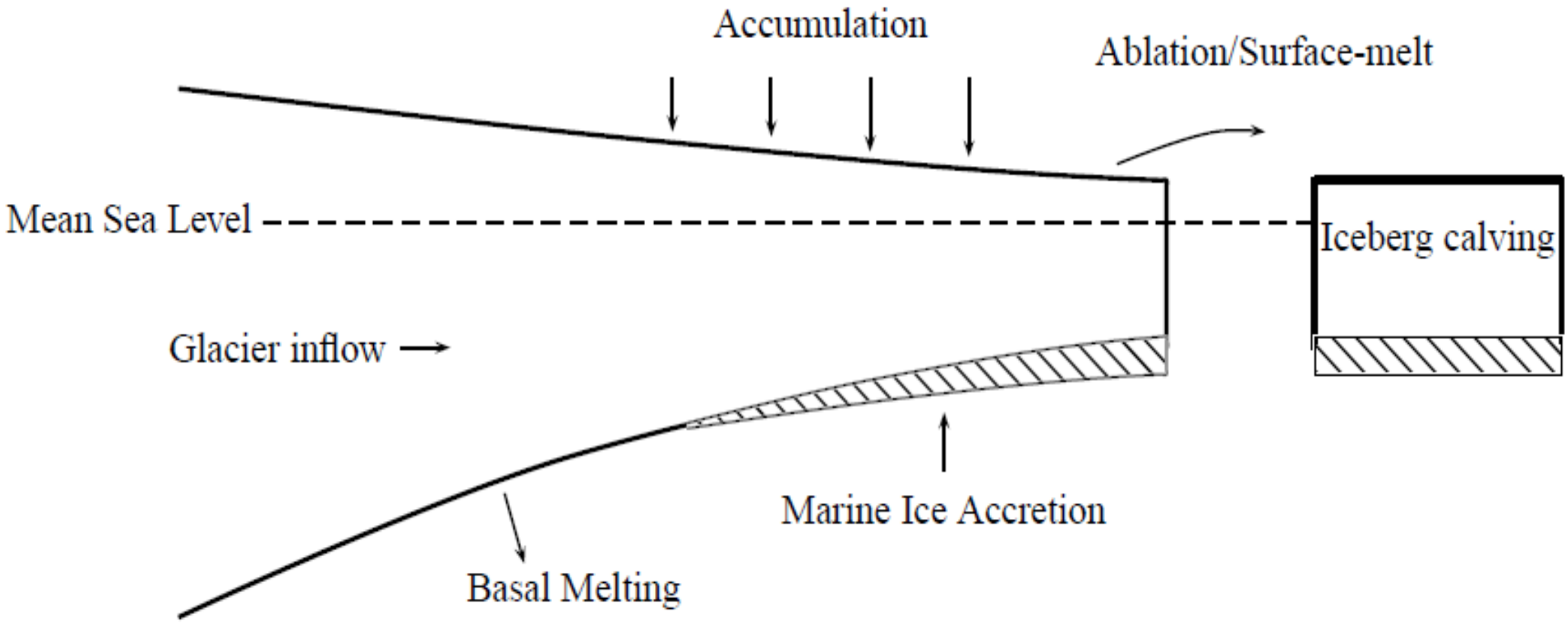
“ The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves …” p 7.

“ Dynamical processes… …could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. **Understanding of these processes is limited and there is no consensus on their magnitude.**” p 17.

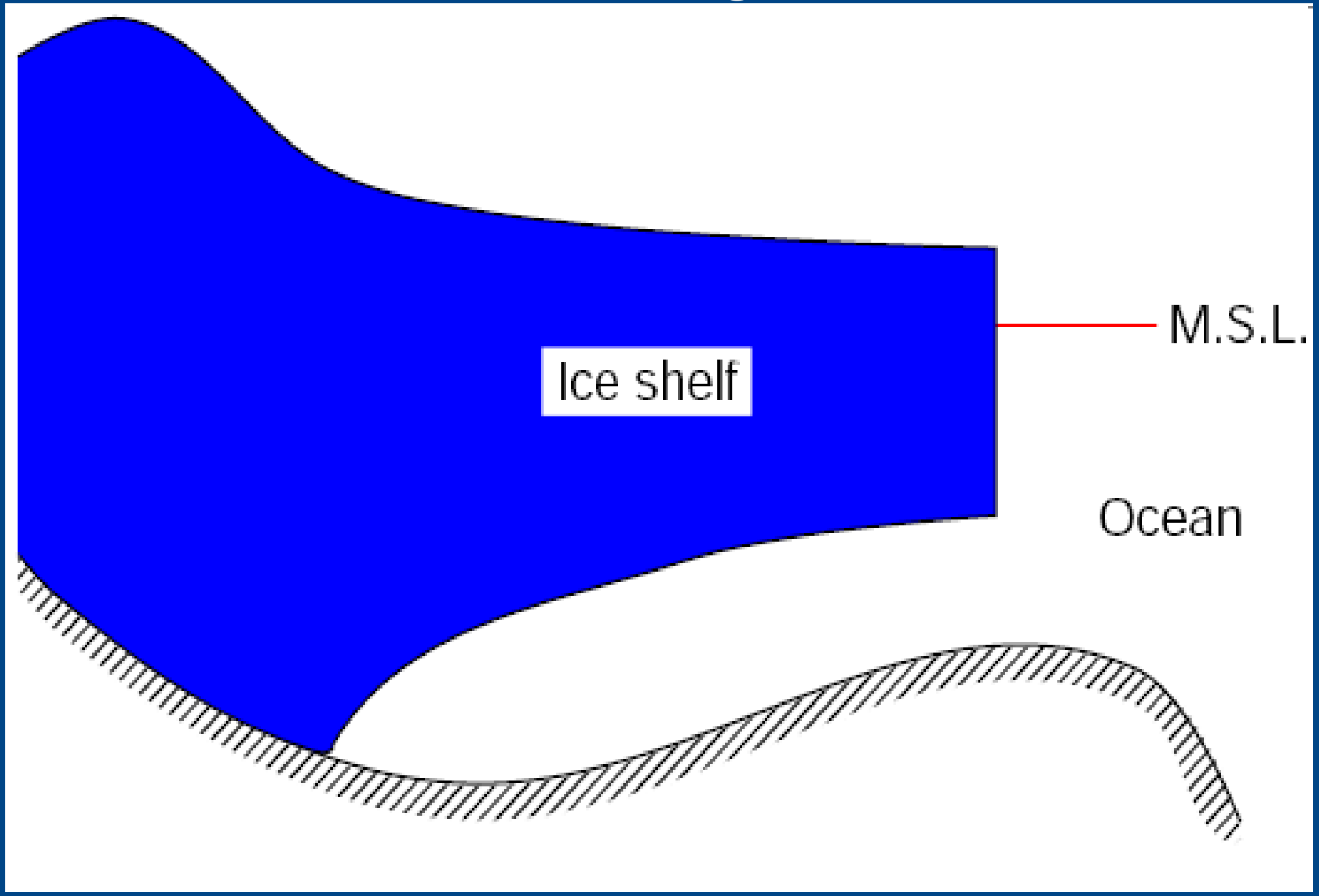
Ice shelves connect the ice sheet to the oceans



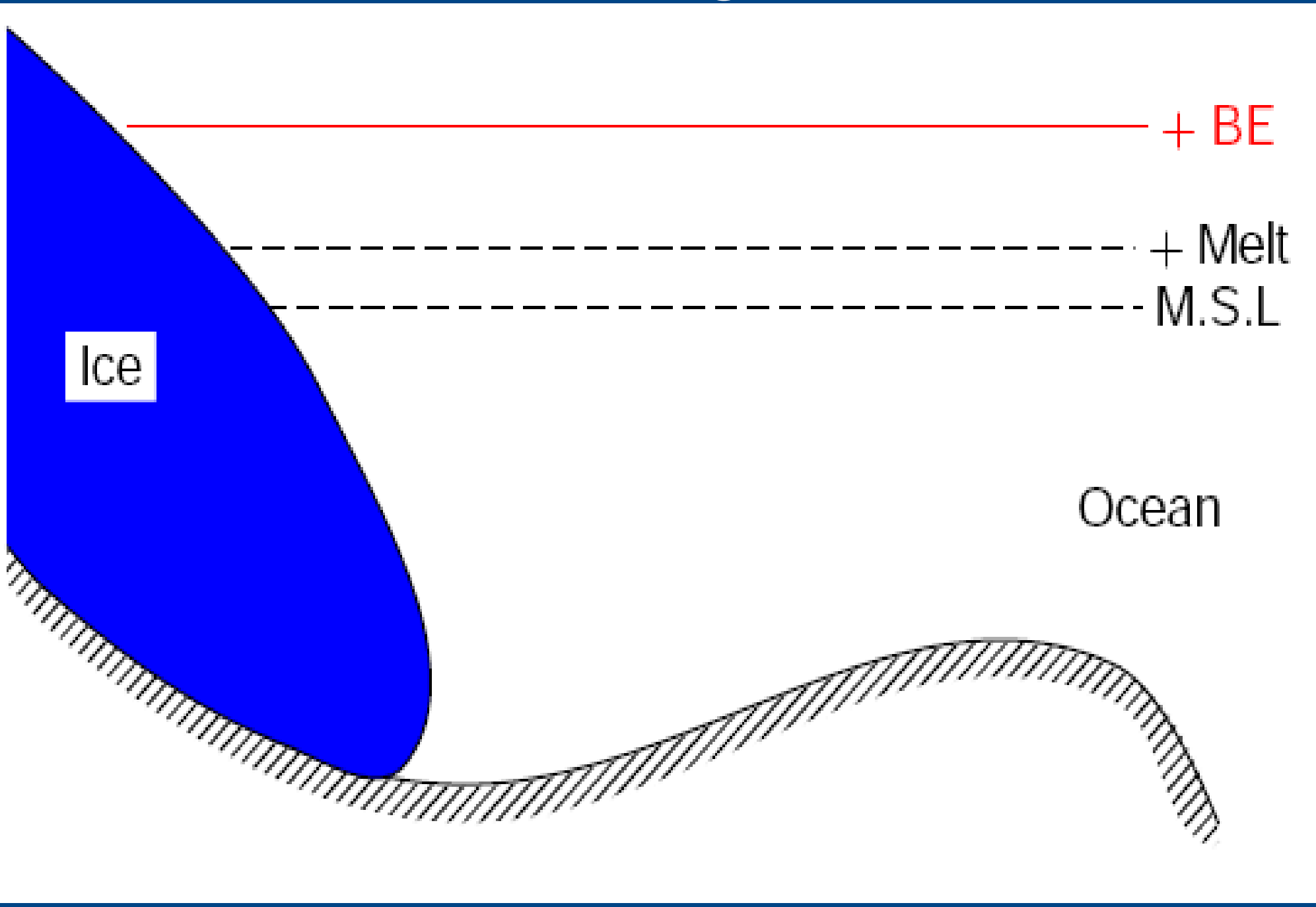
Ice Shelf Mass Balance



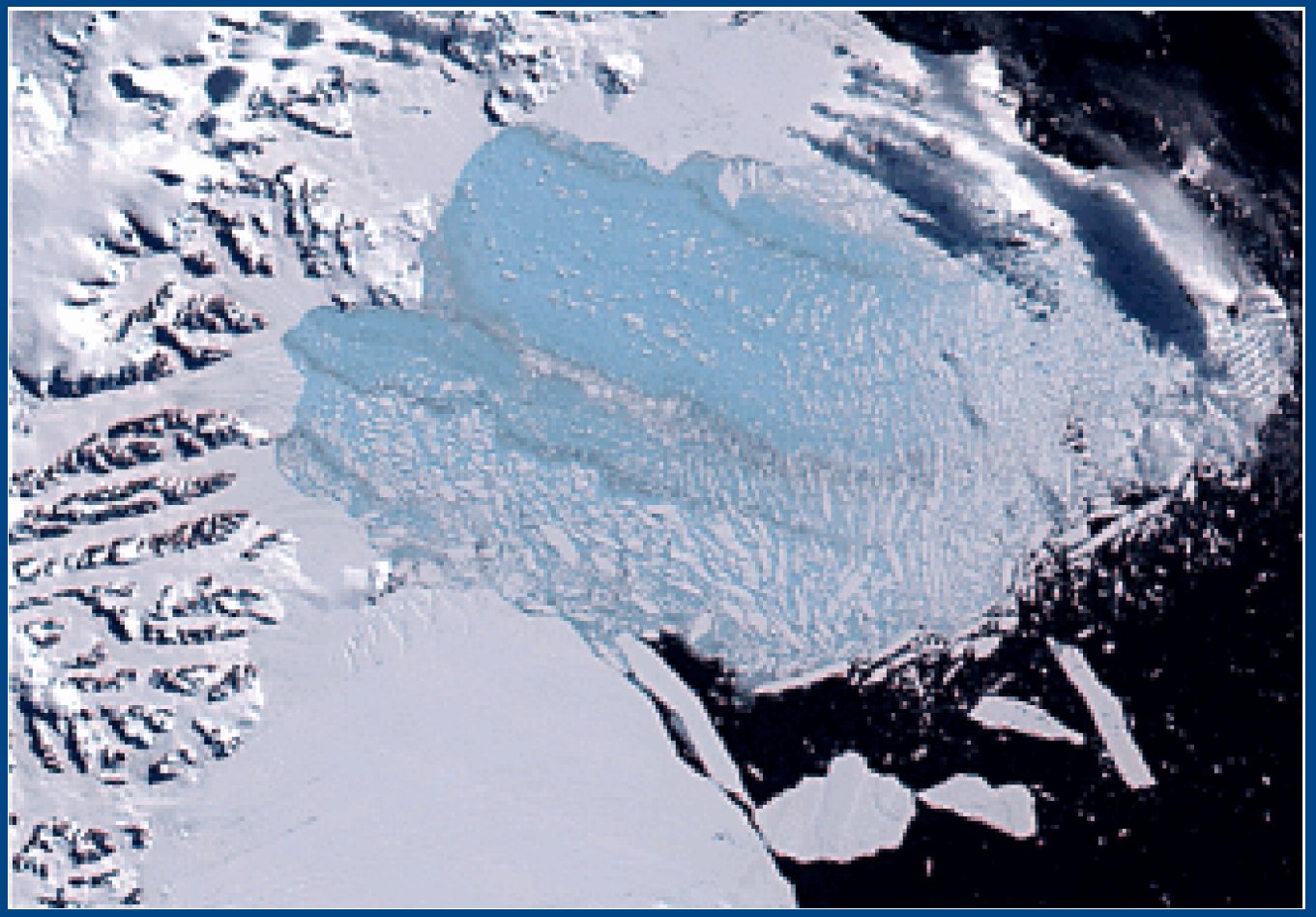
Buttressing effect



Buttressing effect

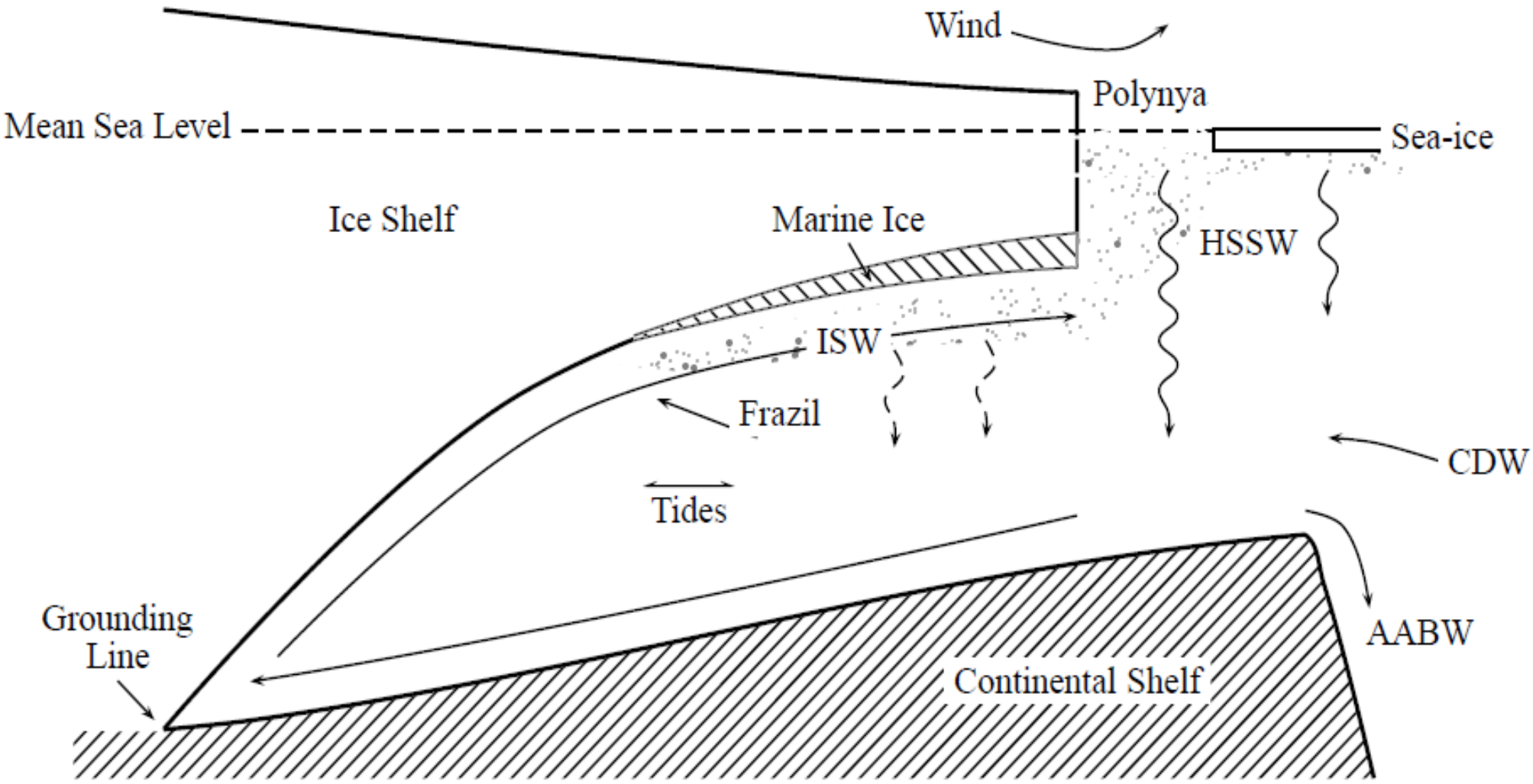


Why?

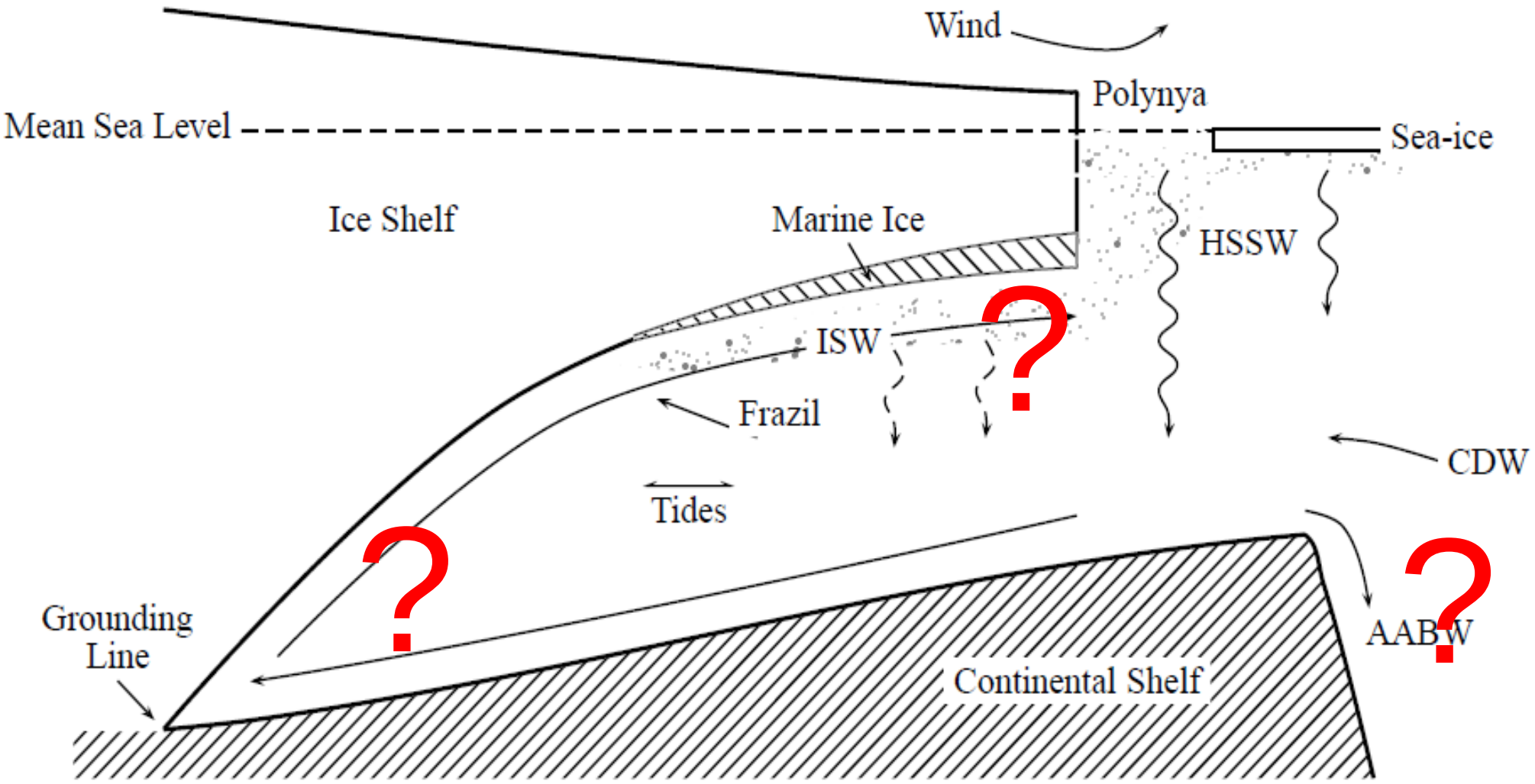


Mid March 2002 (NASA)

Ice-shelf/ocean interaction



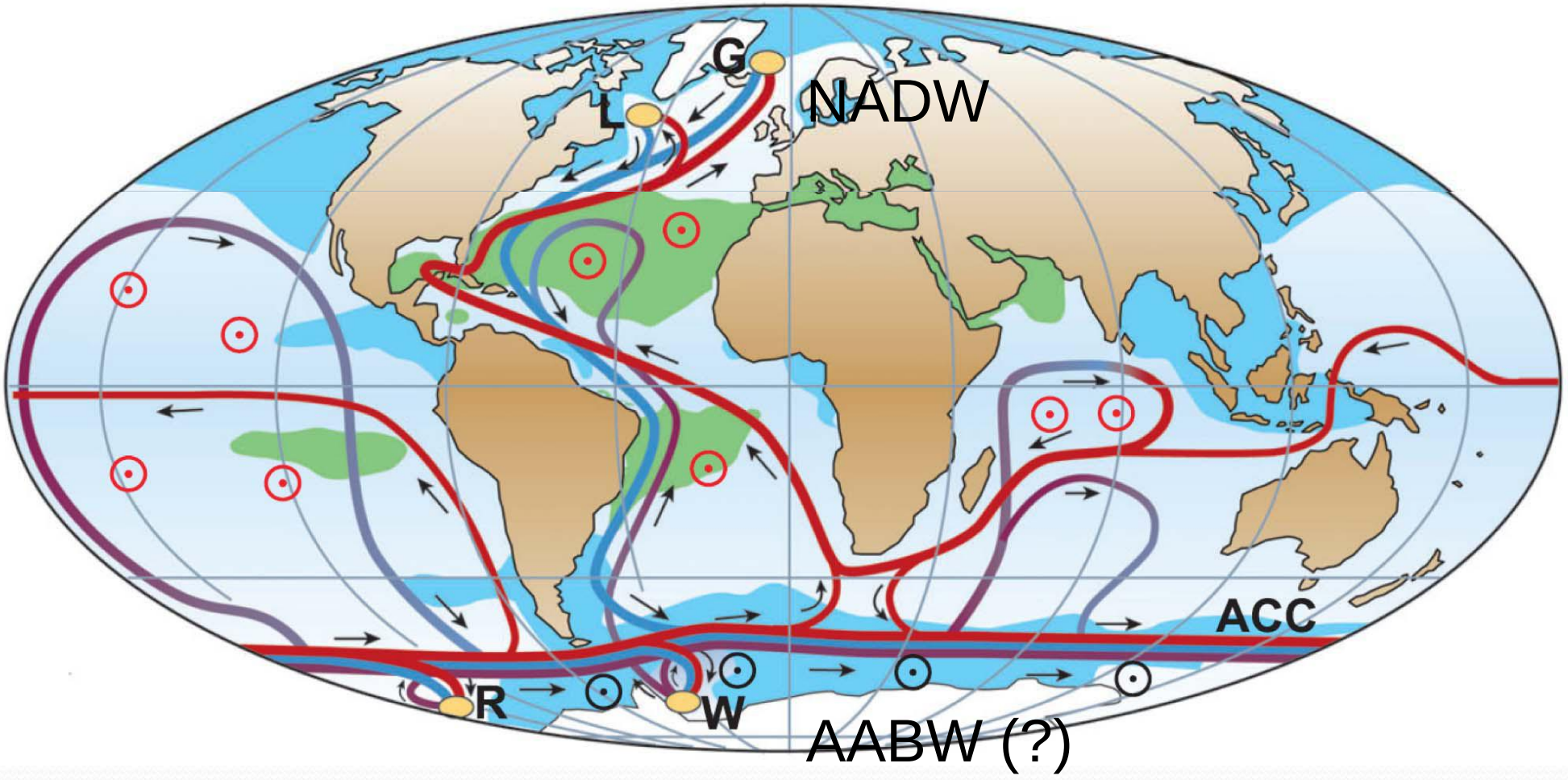
Ice-shelf/ocean interaction



Origin of Jade Icebergs

Global ThermoHaline Circulation

Rahmstorf (2002)



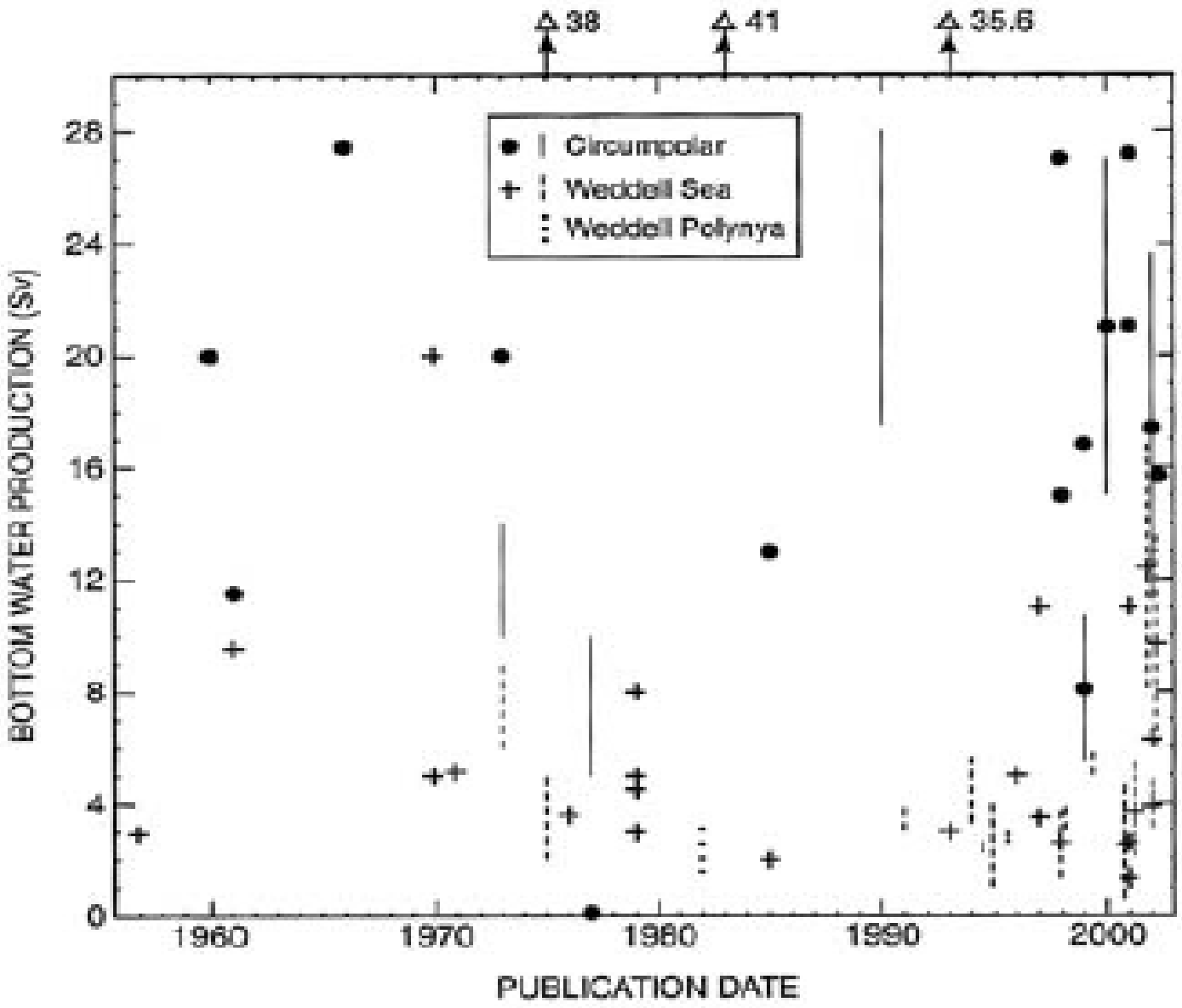
Surface flow
Deep flow
Bottom flow
Deep Water Formation

Wind-driven upwelling
Mixing-driven upwelling
Salinity > 36 ‰
Salinity < 34 ‰

L Labrador Sea
G Greenland Sea
W Weddell Sea
R Ross Sea

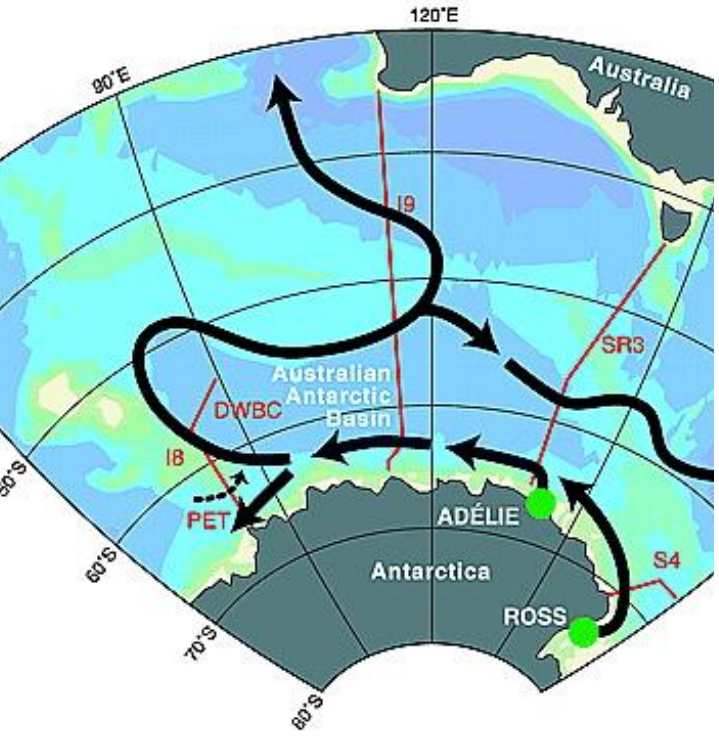
NADW (Bolus transport)

Estimates of AABW production

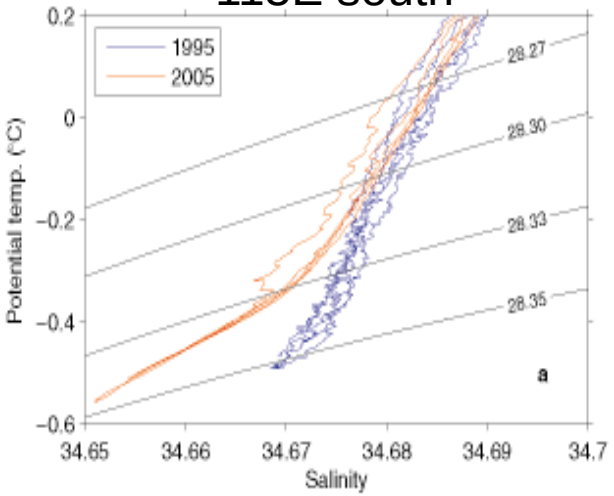


Jacobs 2004

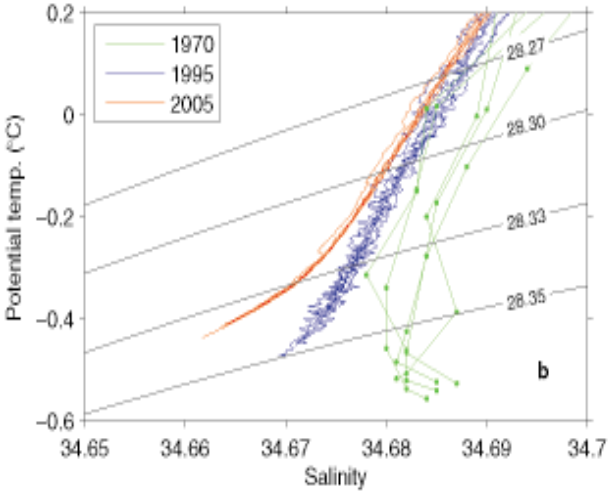
AABW is freshening



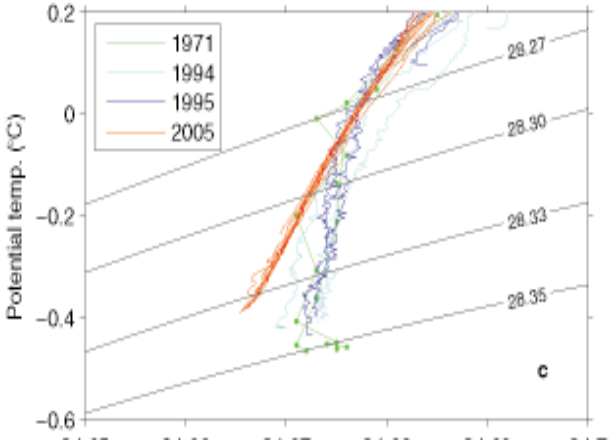
115E south



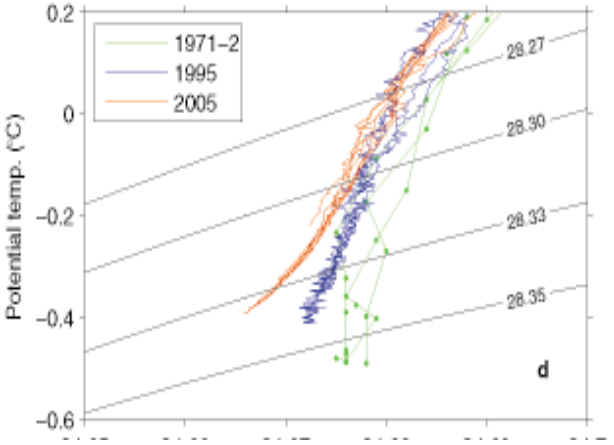
115E north



PET

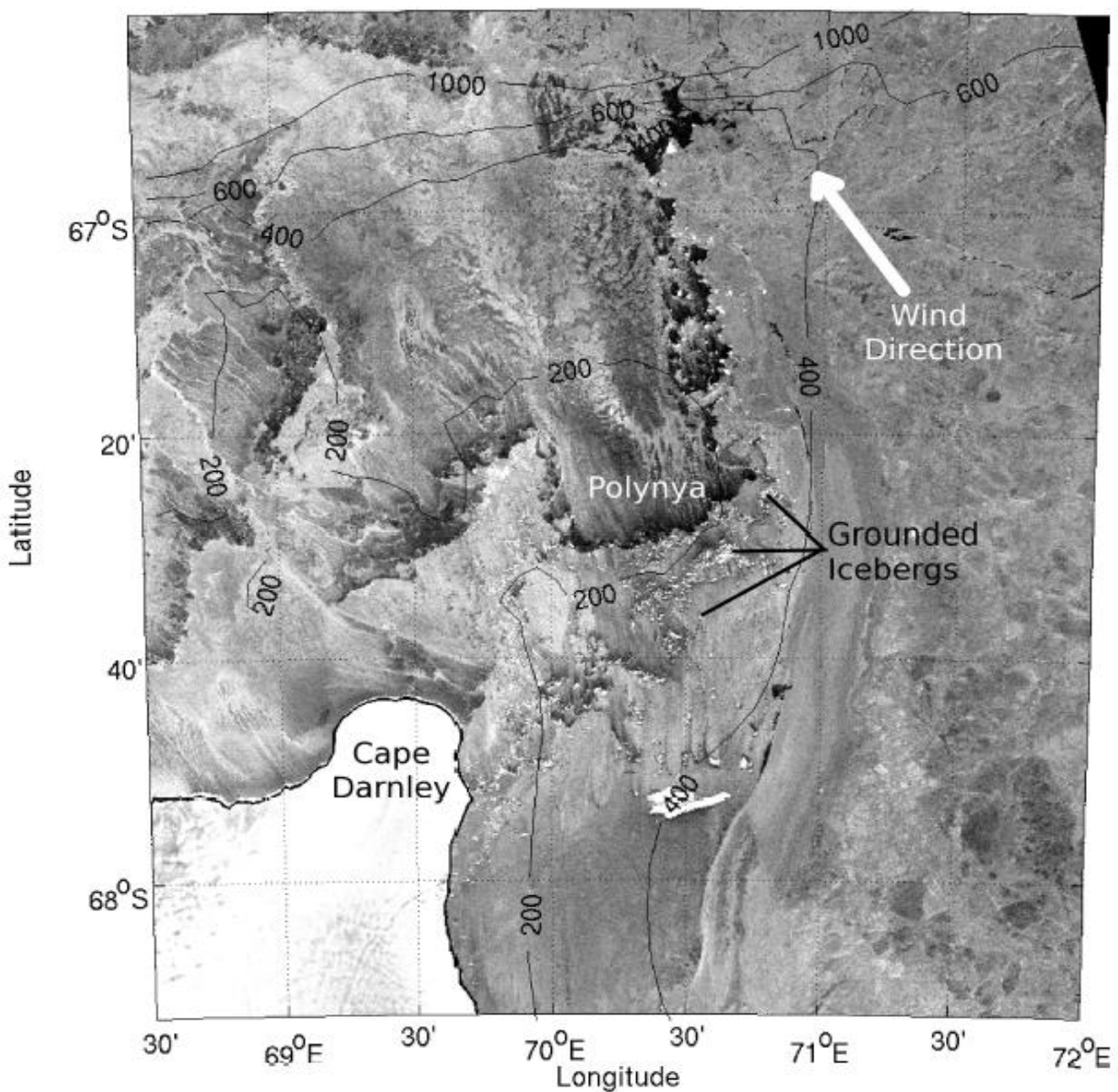


DWBC

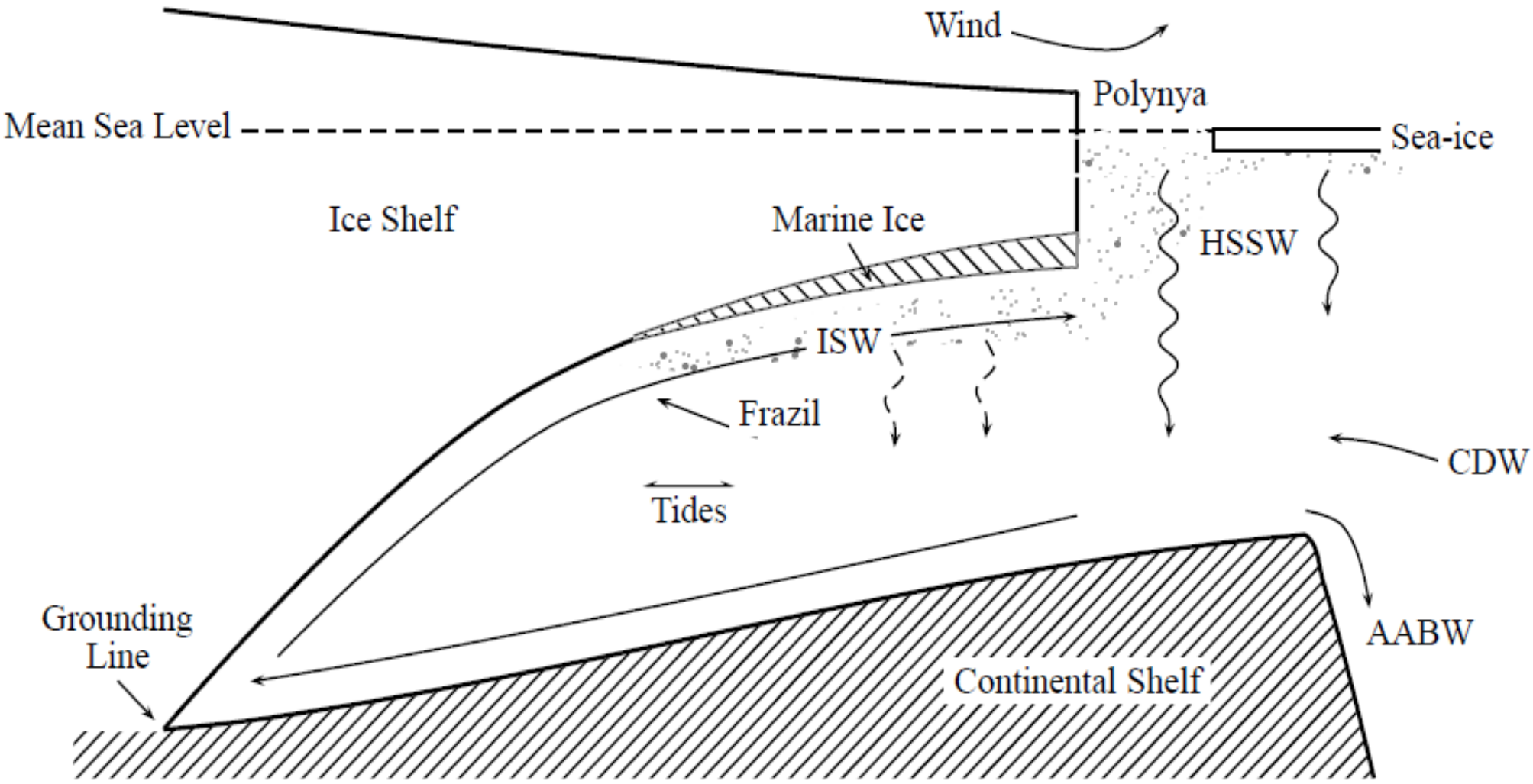


Rintoul 2007

Mechanisms of AABW formation: Polynyas and HSSW



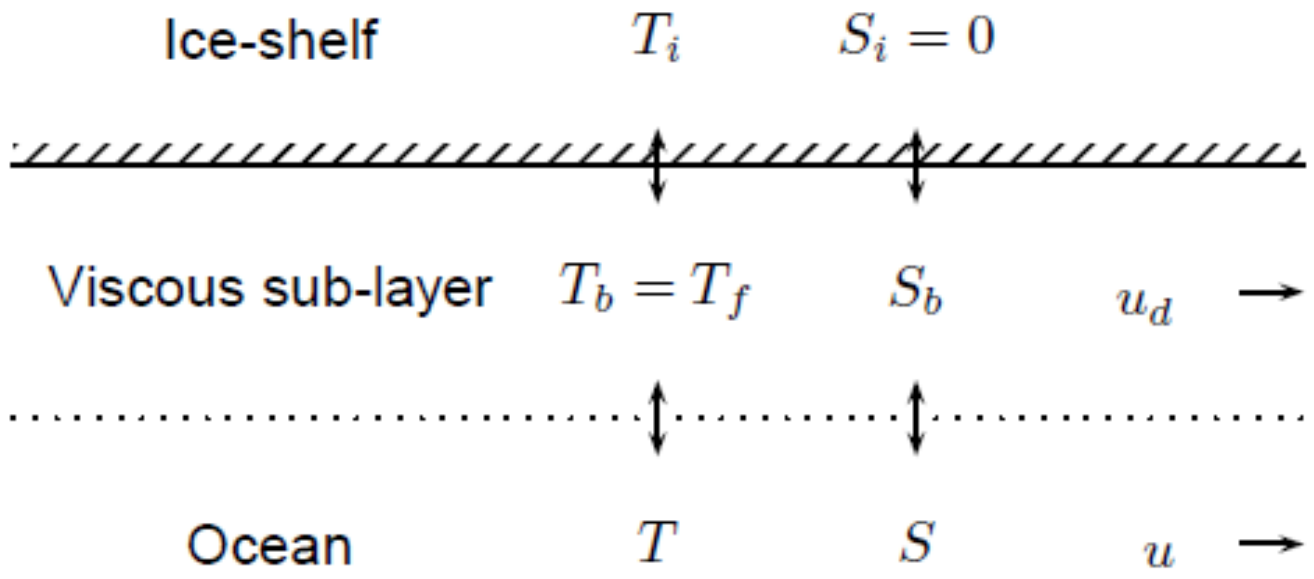
Ice-shelf/ocean interaction



Developing an ice shelf/ocean model

- Mechanical modifications: Adjustment of the surface pressure to account for the floating ice shelf (Already part of ROMS). Depth ranges from 300-2500m below mean sea level
- Thermodynamic modifications:
  - Direct basal ice-ocean interaction
  - Frazil ice dynamics
- Modified equation of state for larger range of θ (Jackett and McDougall 2006)

Basal ice-ocean boundary



$$\rho_i(L - c_i\Delta T)m = \rho c_w \gamma_T (T_b - T)$$

$$\rho_i S_b m = \rho \gamma_S (S_b - S)$$

$$T_f = -5.73 \times 10^{-2} S_b + 8.32 \times 10^{-2} + 7.61 \times 10^{-4} zice$$

Frazil modelling

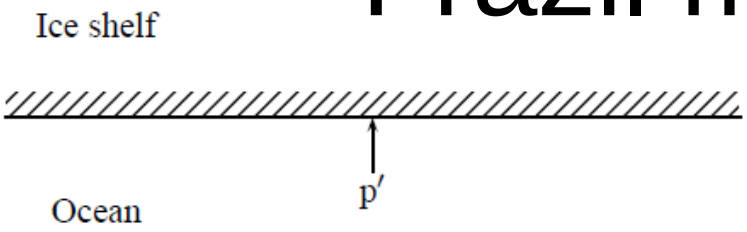
- Following implementation of sediment (Warner et al. 2005) solving advection-diffusion equation:

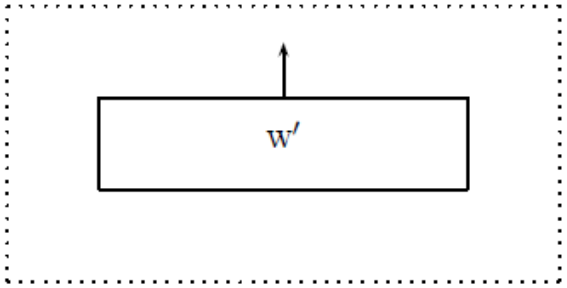
$$\underbrace{\frac{\partial \mathcal{C}}{\partial t}}_{\text{Transient}} + \underbrace{\nabla \cdot (\mathcal{C}\mathbf{v})}_{\text{Advection}} + \underbrace{\mathbf{w}'\frac{\partial \mathcal{C}}{\partial \mathbf{z}}}_{\text{Buoyant rising}} = \underbrace{\nabla \cdot (K \nabla \mathcal{C})}_{\text{Mixing}} + \underbrace{\mathcal{S}}_{\text{Source/Sink}}$$

Frazil tracers are included in ROMS using hijacked sediment code. Modifications:

- Buoyant rising (Morse and Richards (2008)
- S = Primary and Secondary Nucleation, Precipitation, Melting/Freezing
- Modified equation of state to consider ice density

Frazil modelling





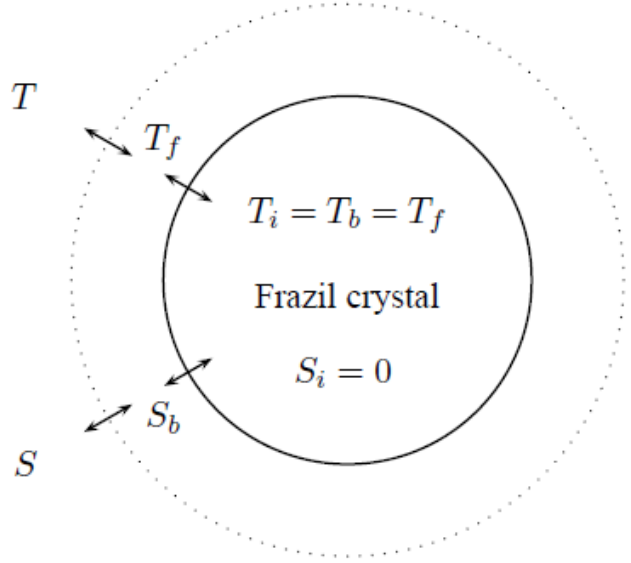
a) Elevation view

$$\rho_i L f' = \rho c_w \gamma'_T \mathcal{A}(T_b - T)$$

$$\rho_i S_b f' = \rho \gamma'_S \mathcal{A}(S_b - S)$$

$$\gamma'_T = \frac{Nuk_T}{ra_r}$$

$$\gamma'_S = \frac{Shk_S}{ra_r}$$

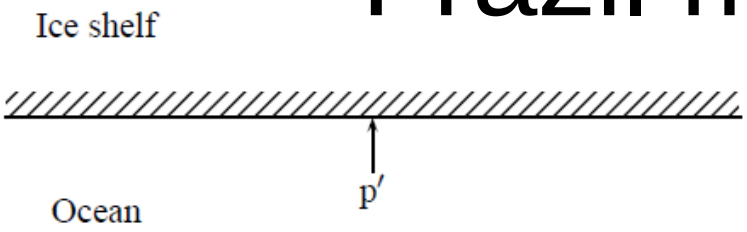


b) Plane view

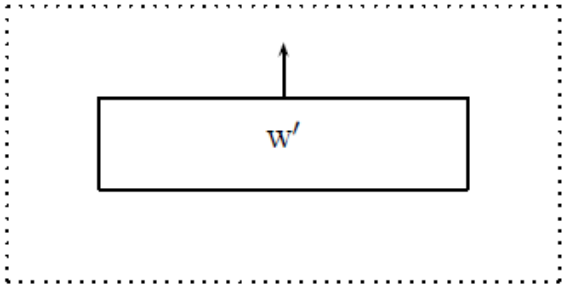
Nu = Nusselt number
Sh = Sherwood number

Nu and Sh both scale with crystal size

Frazil modelling



a) Elevation view

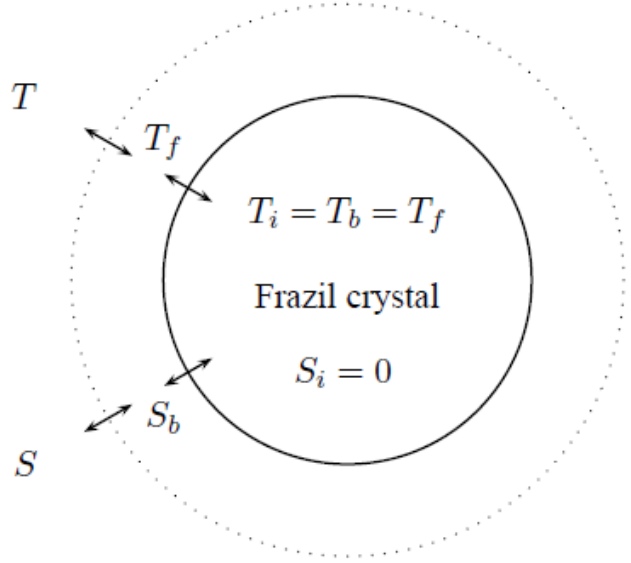


$$\rho_i L f' = \rho c_w \gamma'_T \mathcal{A}(T_b - T)$$

~~$$\rho_i S_b f' = \rho \gamma'_S \mathcal{A}(S_b - S)$$~~

$$\gamma'_T = \frac{Nuk_T}{ra_r}$$

$$\gamma'_S = \frac{Shk_S}{ra_r}$$

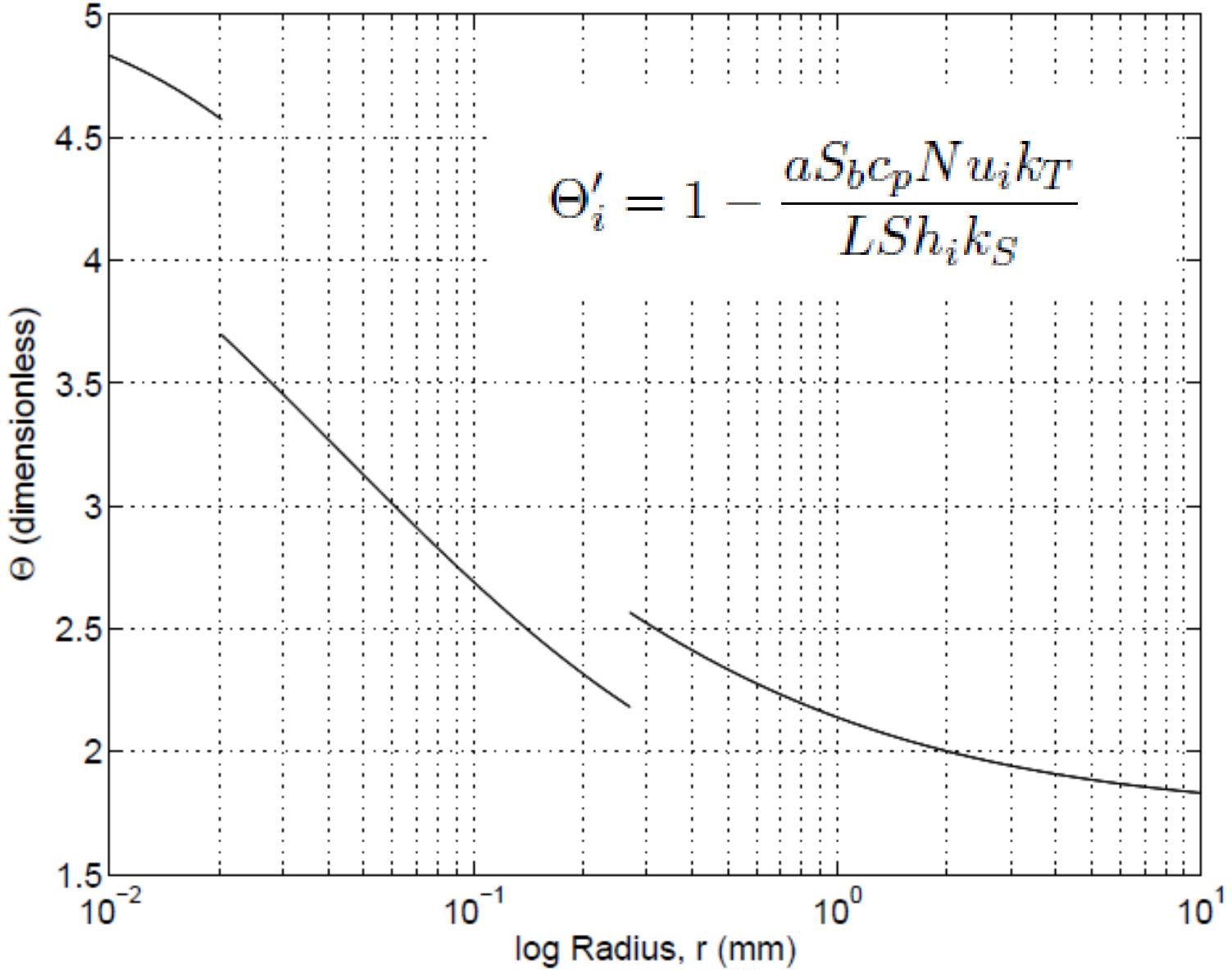


b) Plane view

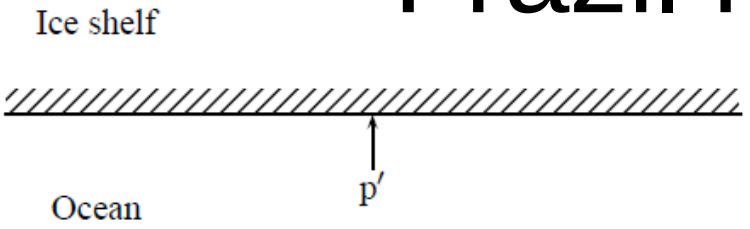
Nu = Nusselt number
Sh = Sherwood number

Nu and Sh both scale with crystal size

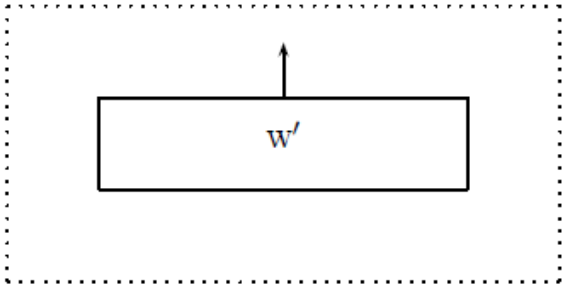
Scaling Factor



Frazil modelling



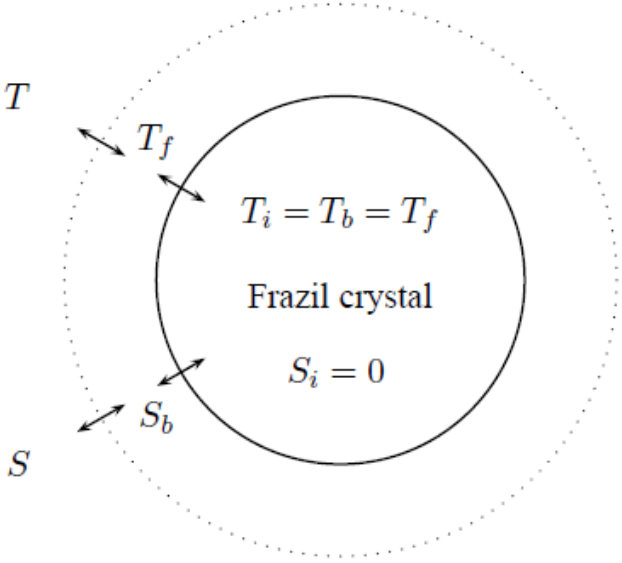
a) Elevation view



$$G_i = \frac{c_p N u_i k_t}{L\Theta_i'}(T_f - T)\frac{2}{r_i^2}C_i$$

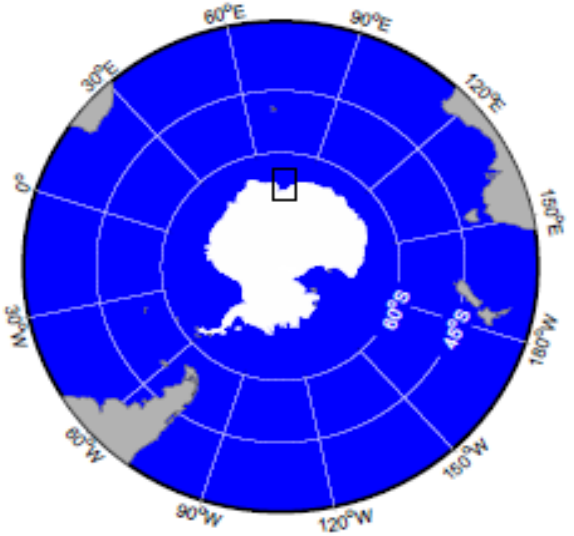
$$M_i = \frac{c_p N u_i k_t}{L\Theta_i'}(T_f - T)\frac{2}{r_i}\left(\frac{1}{r_i} + \frac{1}{2a_r r_i}\right)C_i$$

b) Plane view



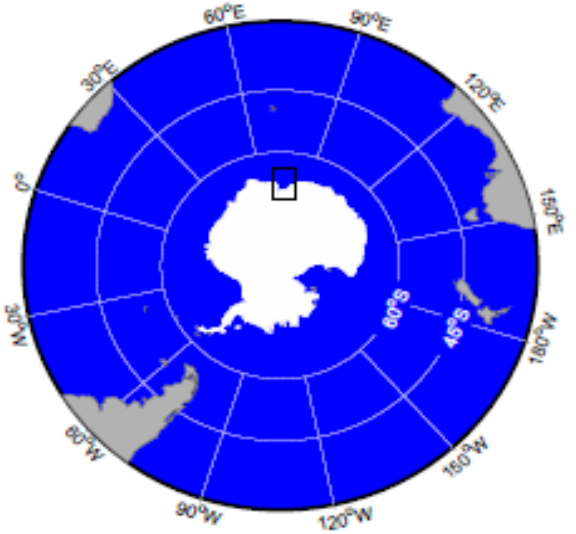
w' and p' follow
Jenkins and Bombosch (1995) and
Holland and Feltham (2005)

The Amery Ice Shelf Ocean Model

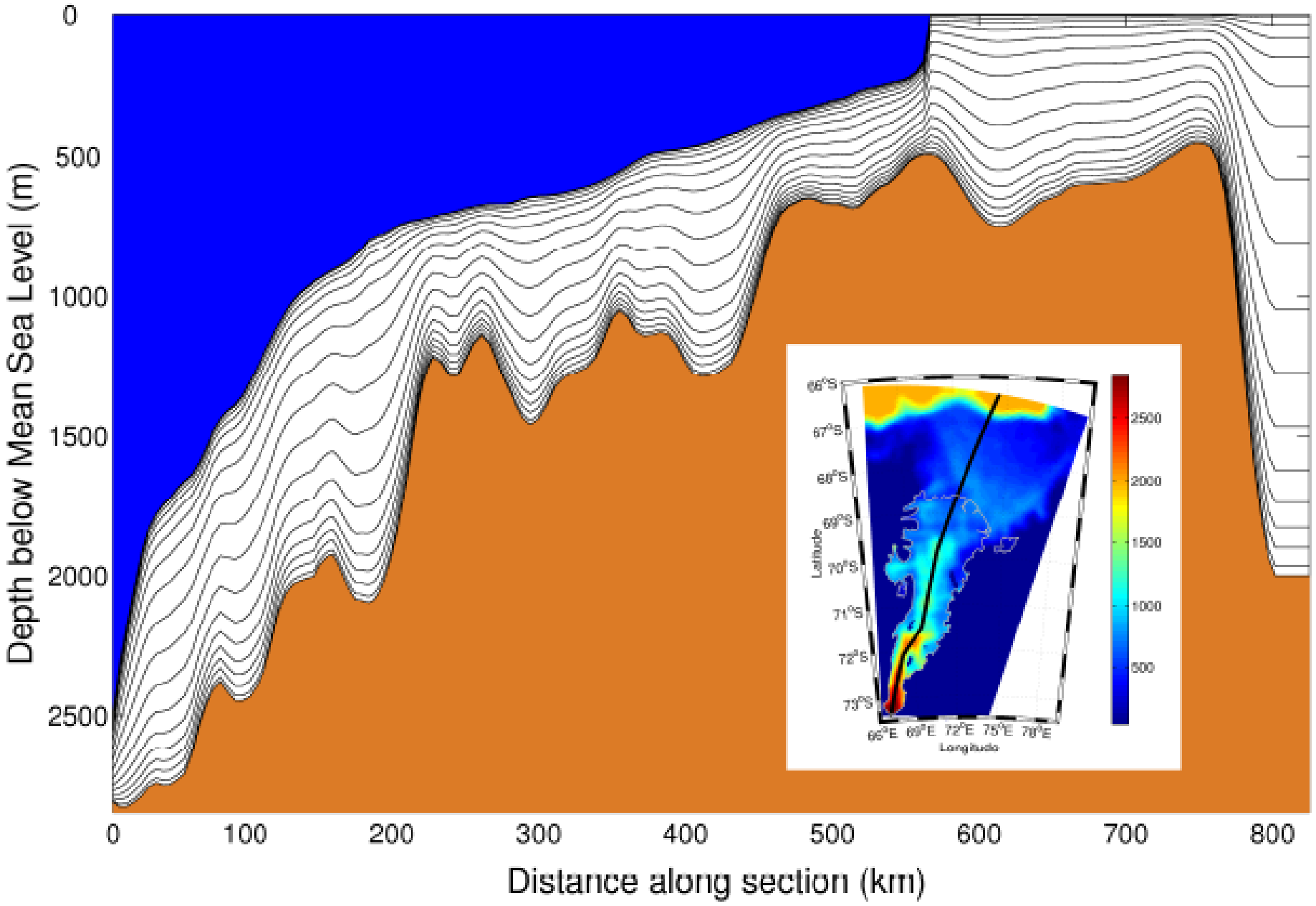


- Based on the Rutgers version of ROMS: Regional Ocean Modeling System (Hernan Arango)
- Shchepetkin and McWilliams (2005)

The Amery Ice Shelf Ocean Model



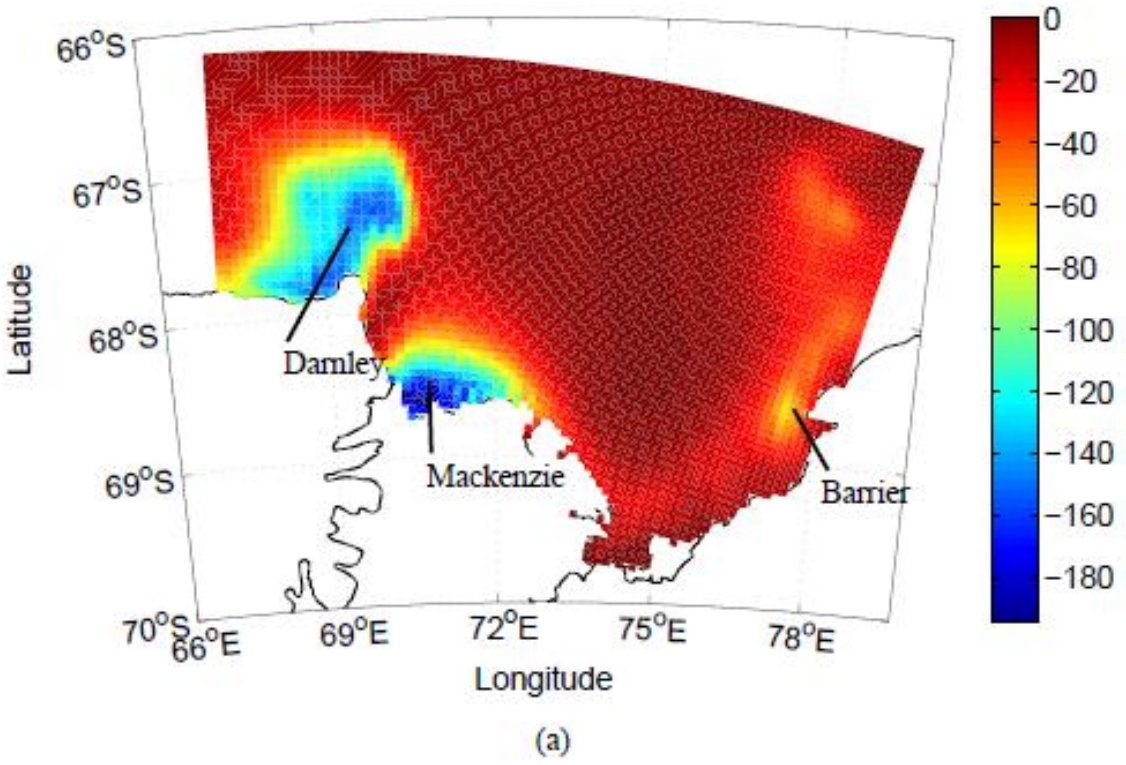
- Time stepping: 600 seconds on baroclinic and 20 seconds on barotropic
- Run time 1 week on 16 cpus (Computationally intensive)
- 60 % longer using 5 frazil size classes
- Geometry: Galton-Fenzi and others (2008)



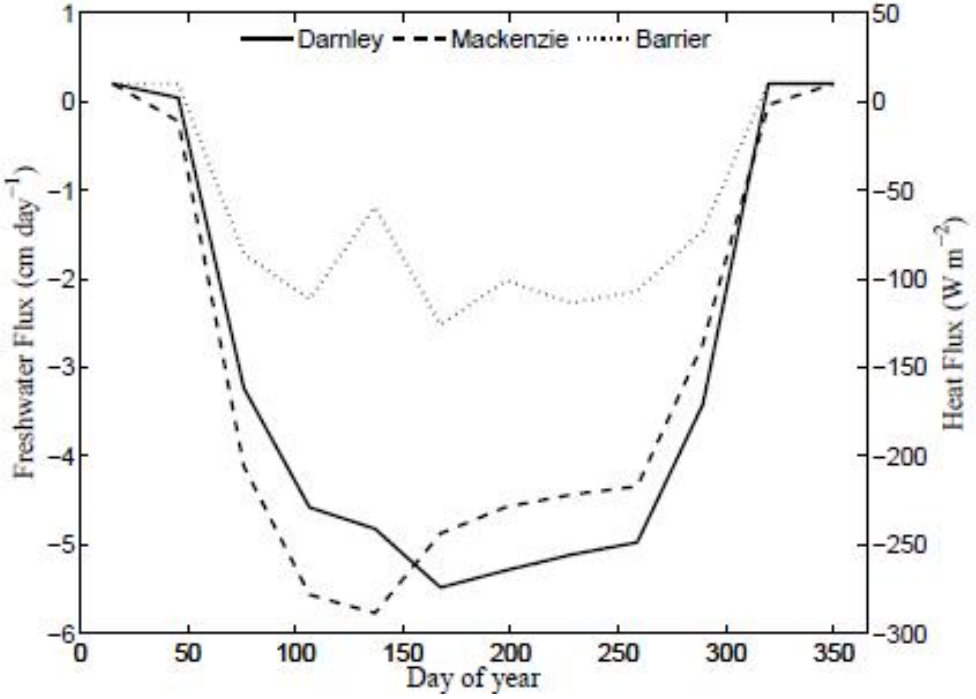
- 171x83 Horizontal grid cells. 16 Vertical layers. Polar grid $\sim$ 2 to 5 km

Forcing

- Following Dinniman and others (2007) JGR:
  - Imposed sea ice from Tamura (2007). Heat and salt fluxes computed from thermodynamic calculation of ice freezing or melting, but ice is not accumulated or transported
  - Daily wind stress and wind speed from NCEP2 reanalysis, which compares well with available AWS observations
- Tidal forcing – TPXO6.2
- Lateral boundaries forcing with climatology from ECCO2 global model.



(a)

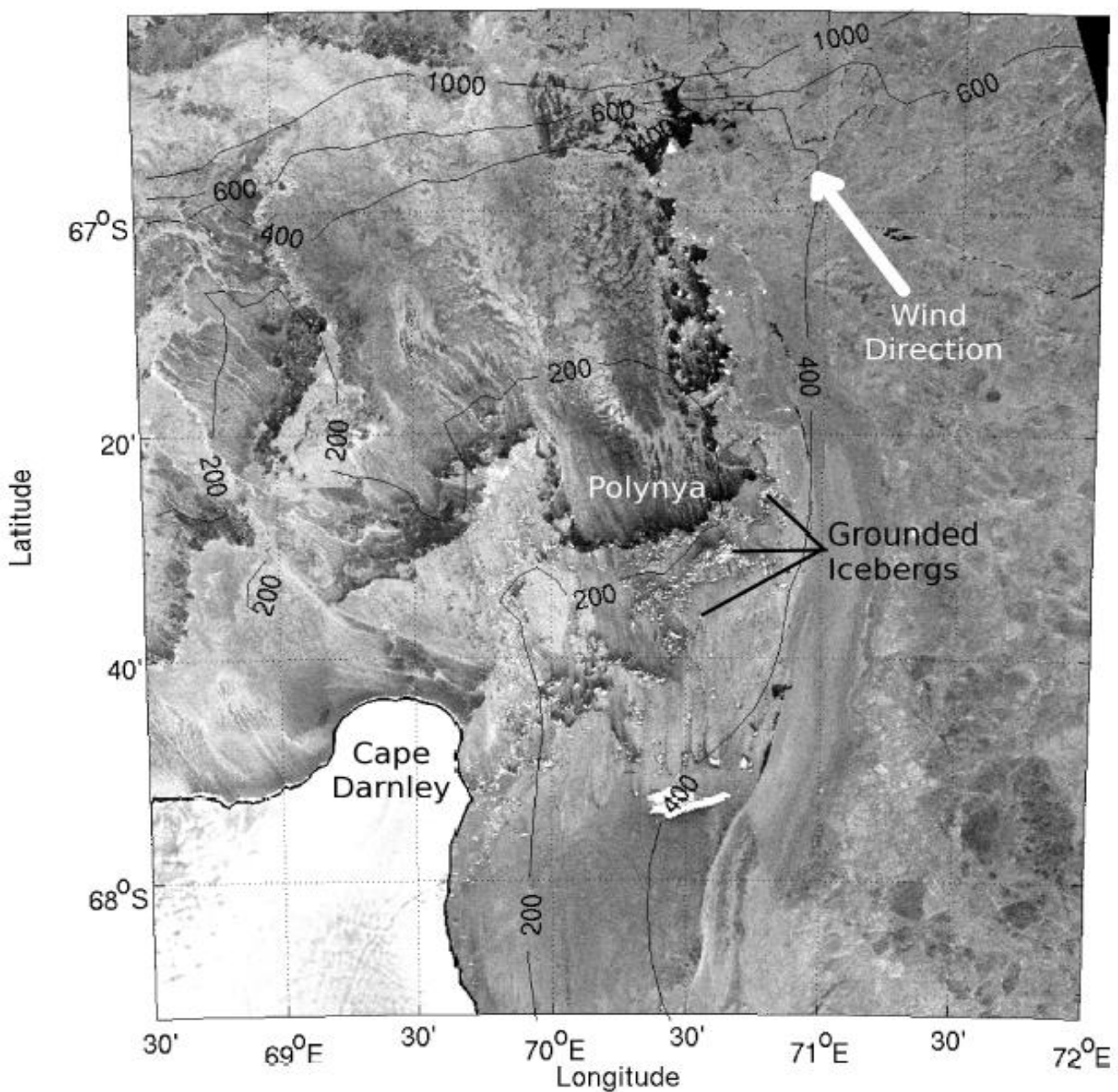


Polynyas in the region:

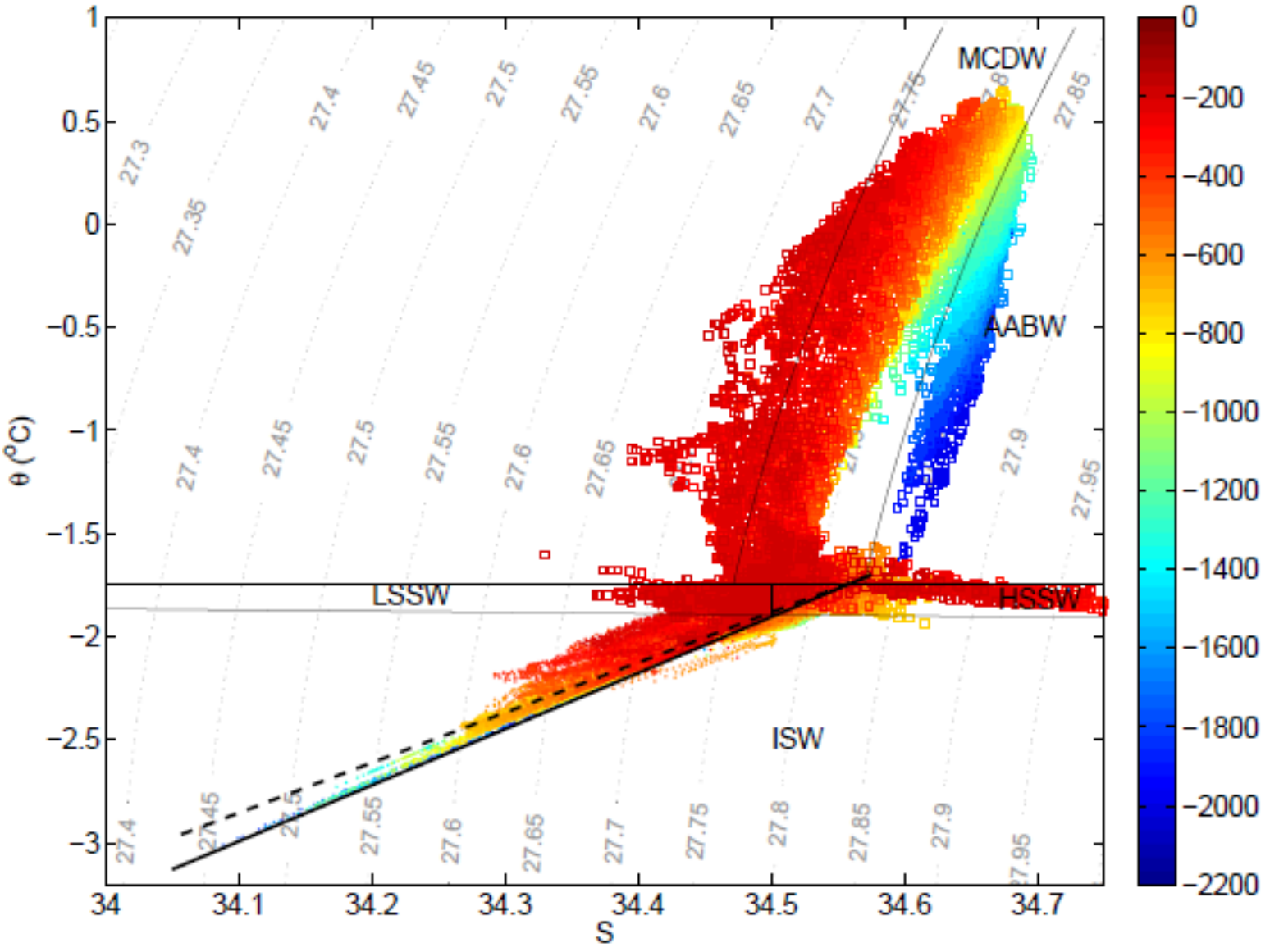
A source of AABW (?)

Tamura (2007)

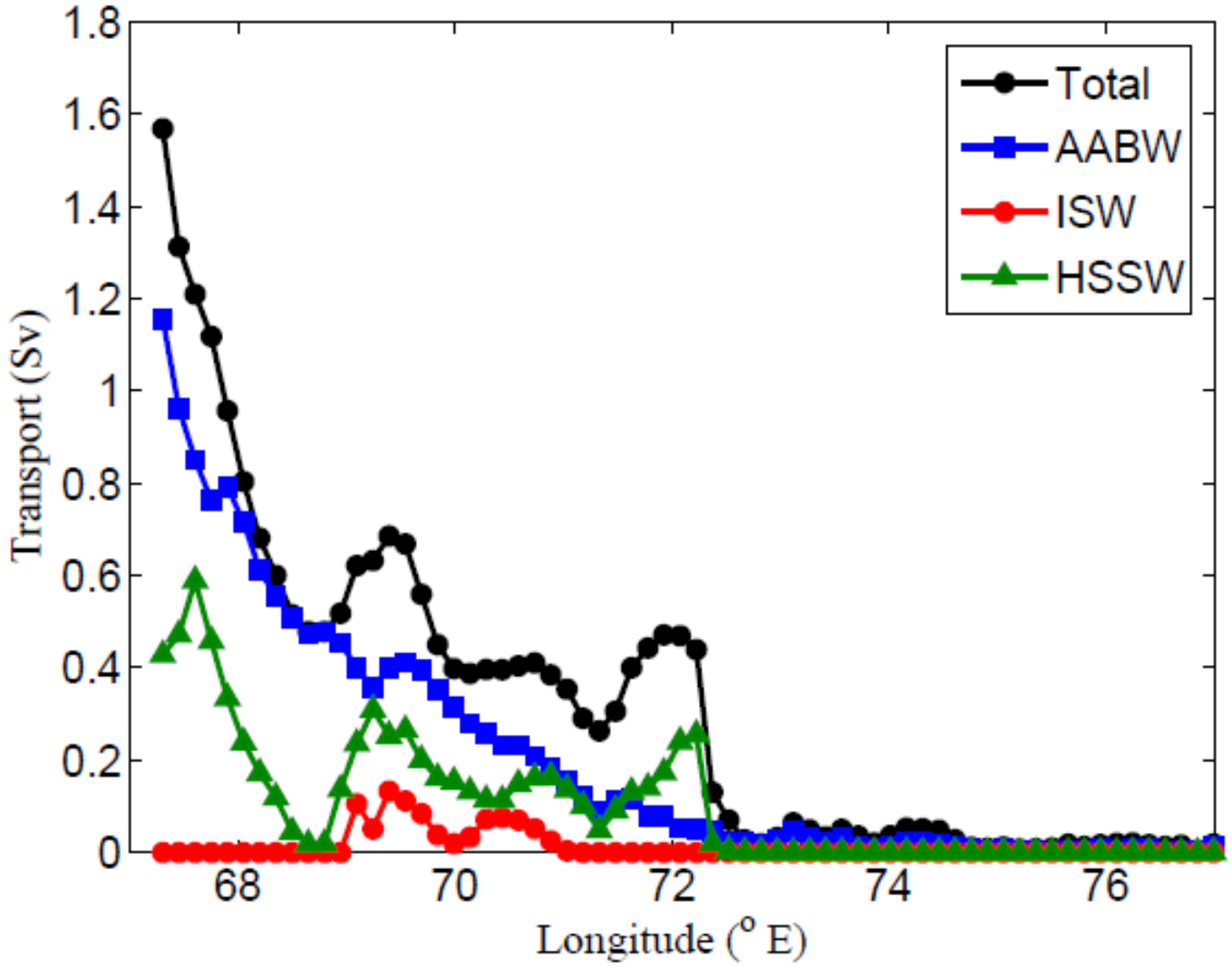
Mechanisms of AABW formation: Polynyas and HSSW



AABW formation



AABW formation



Observations suggest ~ 1 Sv in the vicinity of the Amery (Meijers et al. 2009)

Seasonal variability

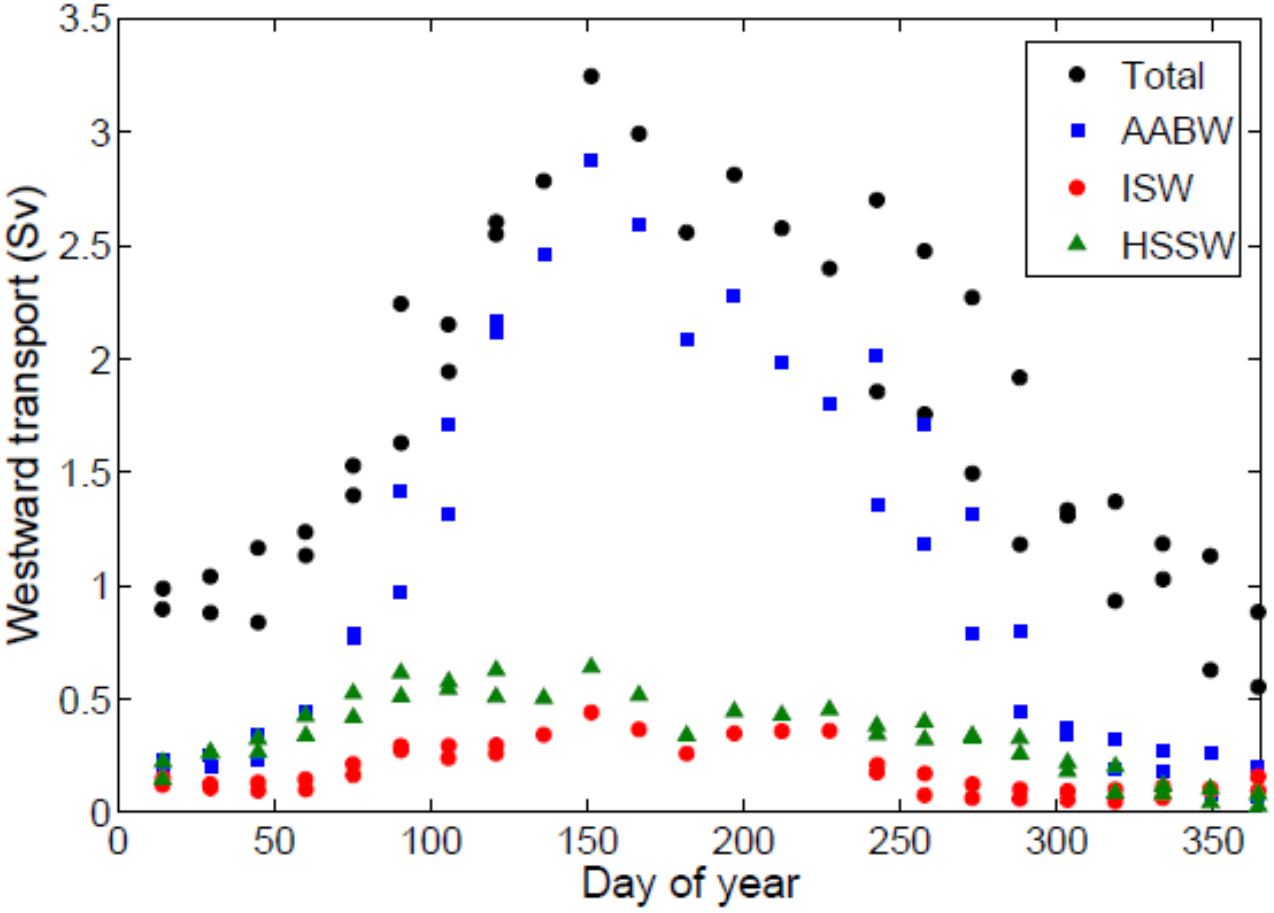
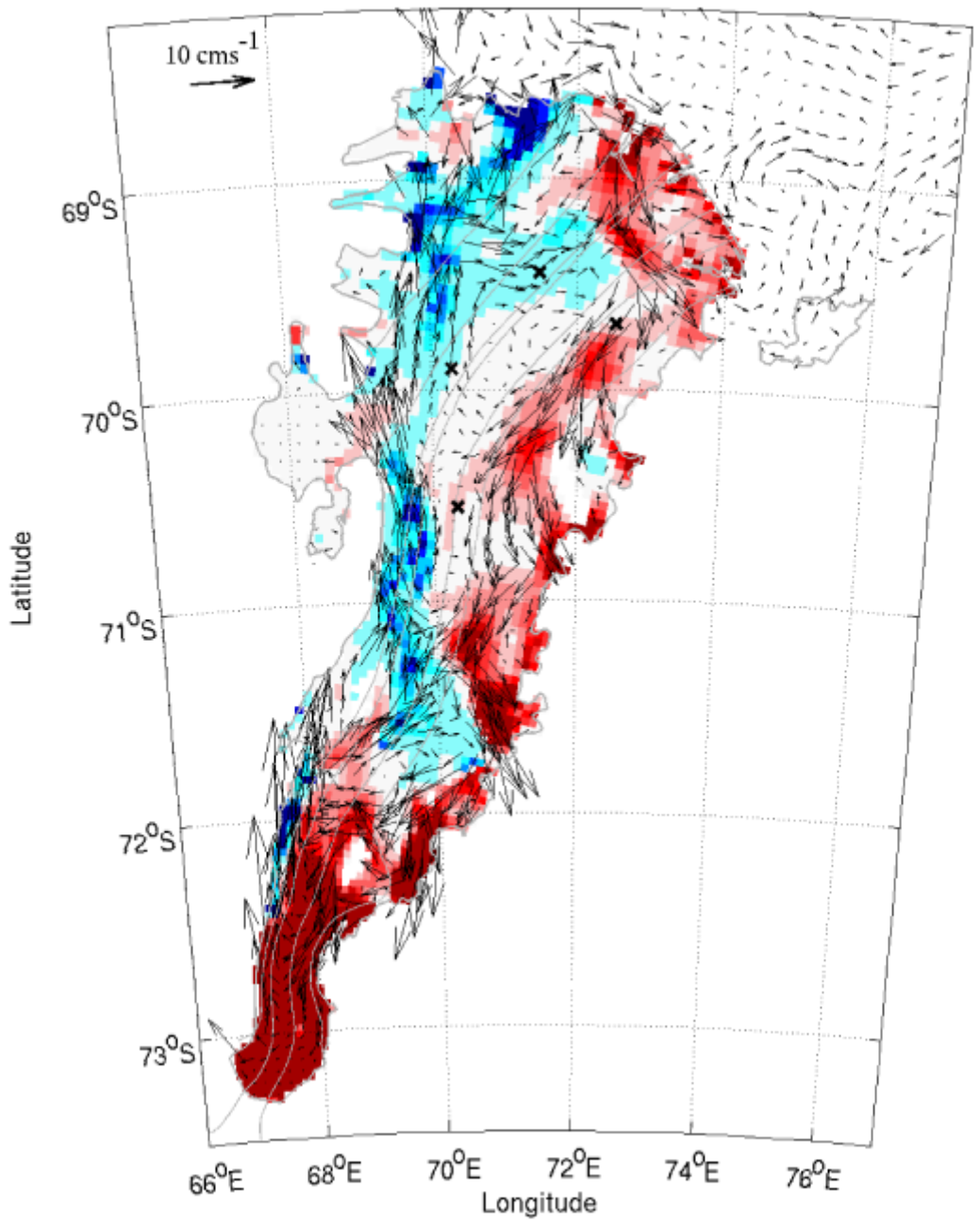
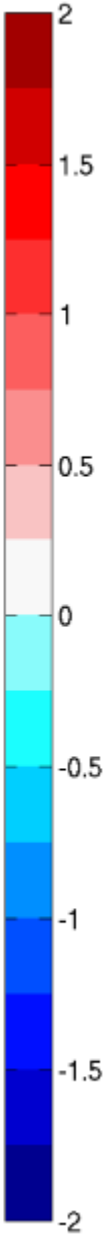


Figure 6.17: The annual-averaged westward transport (sv) of watermasses on the continental slope, for AABW (blue), ISW (red), HSSW (green) and the Total (black).

Melt (+ve)/Freeze (m/year) and depth averaged currents





Model:

•Melting: ~50 Gt/year

• Refreezing: ~ 5.3 Gt/year

• Net: ~ 45 Gt/year

• Frazil accretion: ~70 %

Observations:

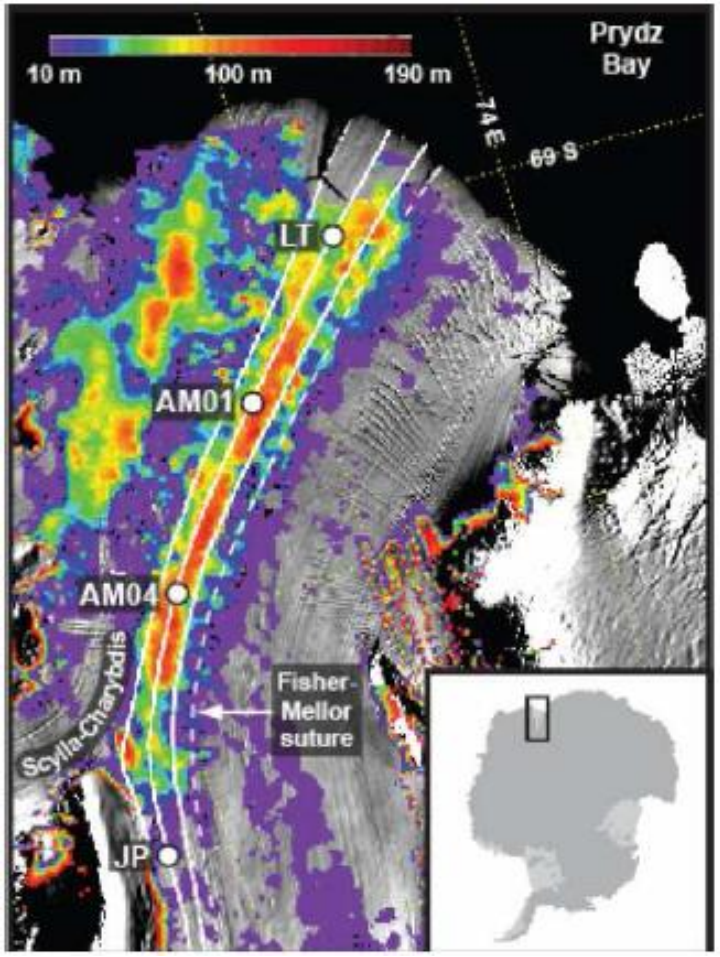
• Net melt: 55.6 +- 12.6 Gt/year

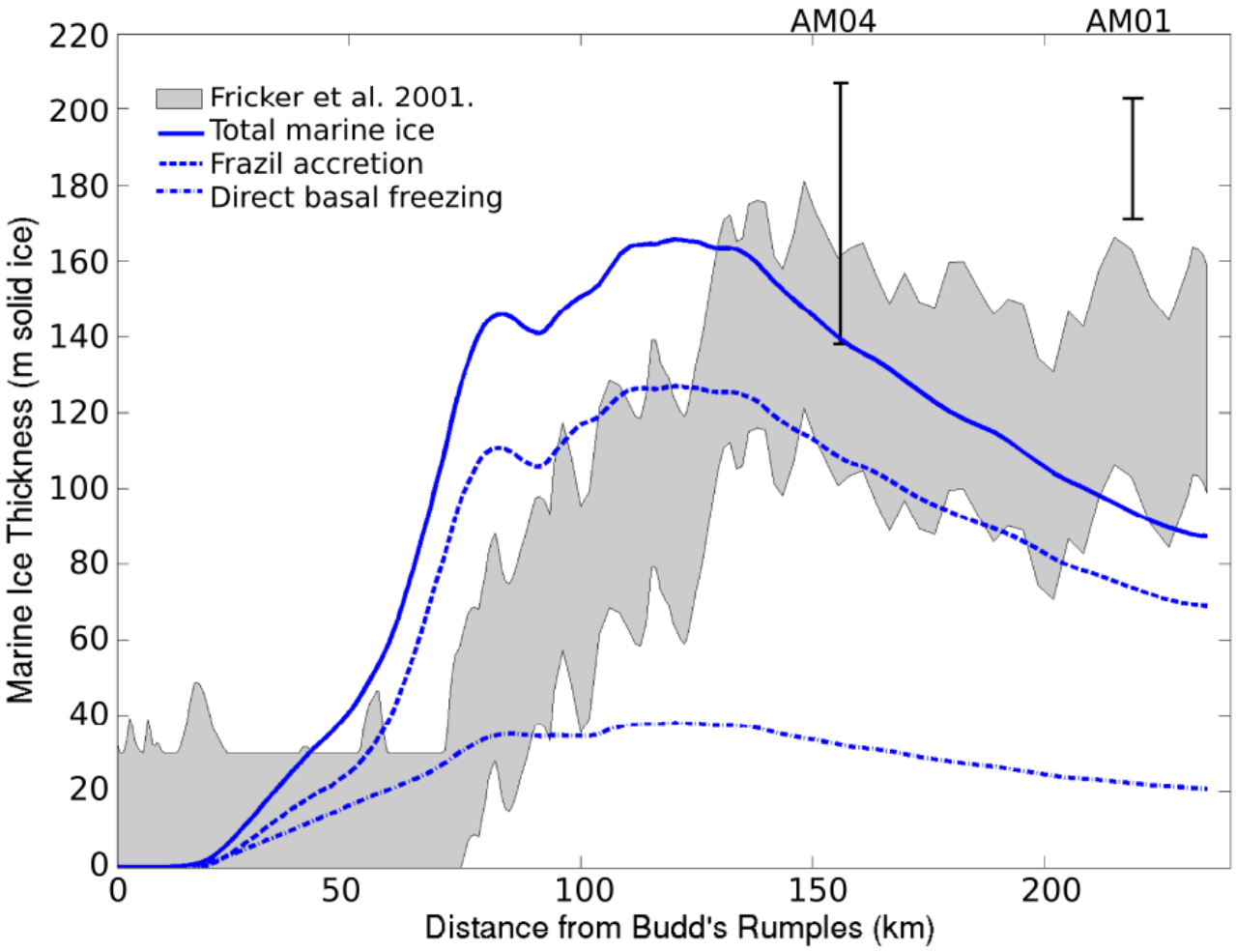
• Glaciers: 88.9 +-9 Gt/year
Wen et al. (2008)

• Accumulation: 11.3 +-0.7 Gt/yea
Arthern et al.(2006)

• Calving: 44.6 +-9.3 Gt/year

Marine Ice Accretion





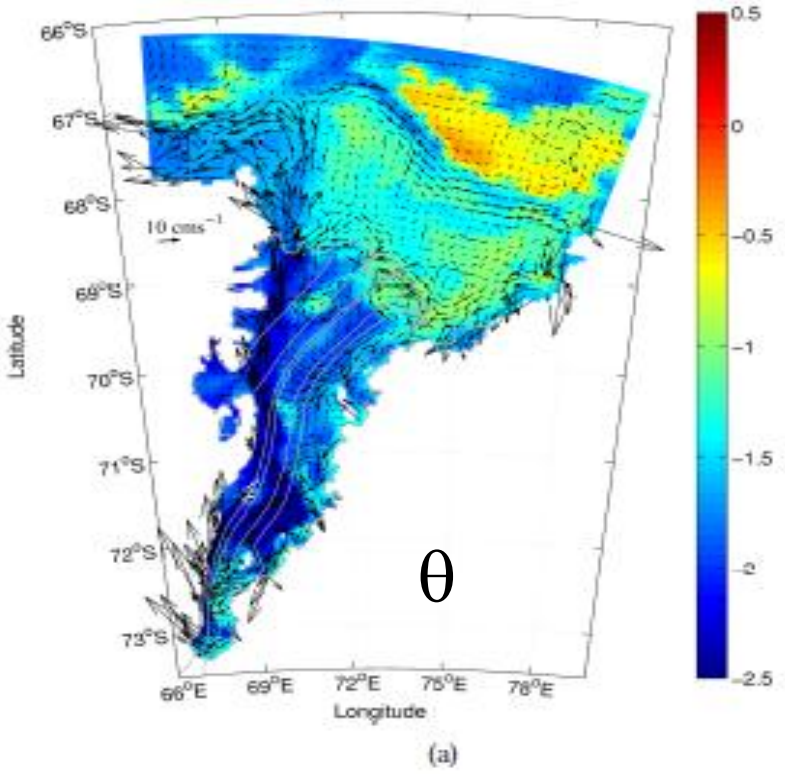
With and without frazil model

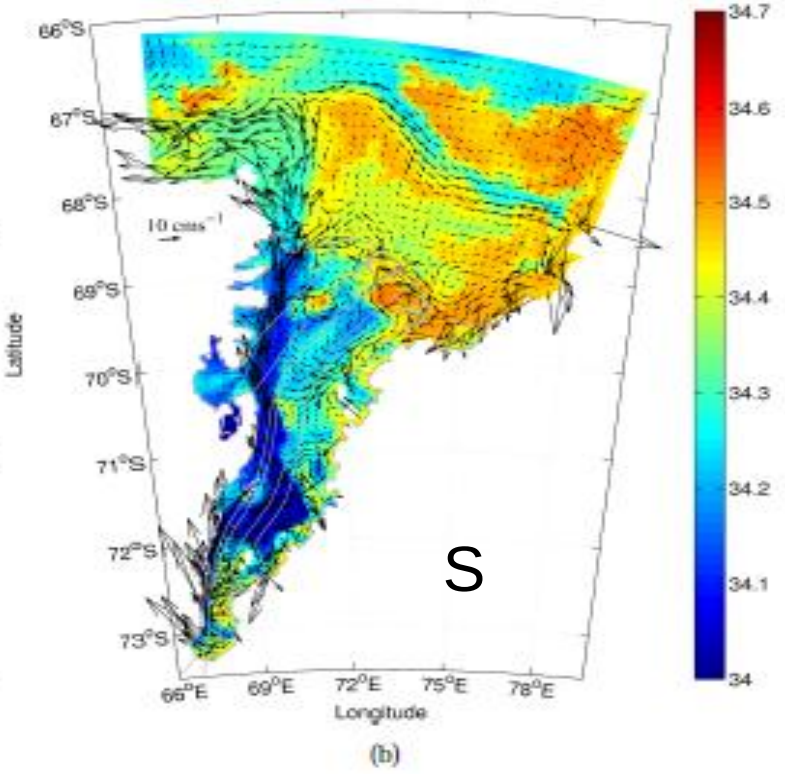
Table 6.5: Model estimates of the various basal mass balance components for the AIS. Net = Melt-Freeze (Gt year^{-1}). The total refreezing for the reference experiment is comprised of 1.64 Gt year^{-1} of direct basal refreezing and 3.62 Gt year^{-1} of frazil accretion.)

Model	Net	Melt	Freeze
Reference	45.63	50.89	5.26
Without Frazil	50.9	52.97	2.07
Glaciological Observations	55.6 ± 12.6	61.6 ± 12.6	$\sim 6^{\dagger}$

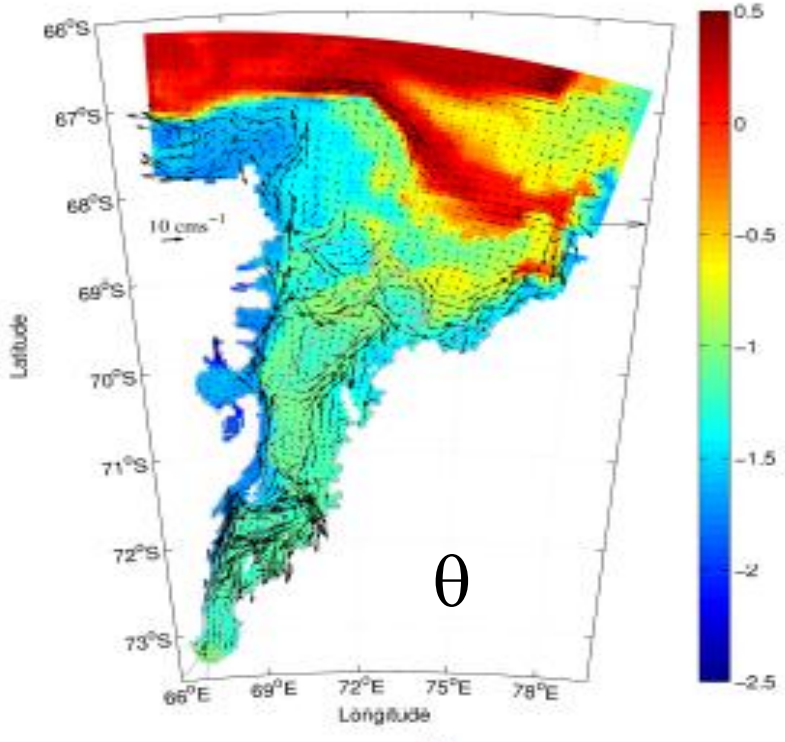
† Personal communication: Roland Warner, ACE CRC (2009)

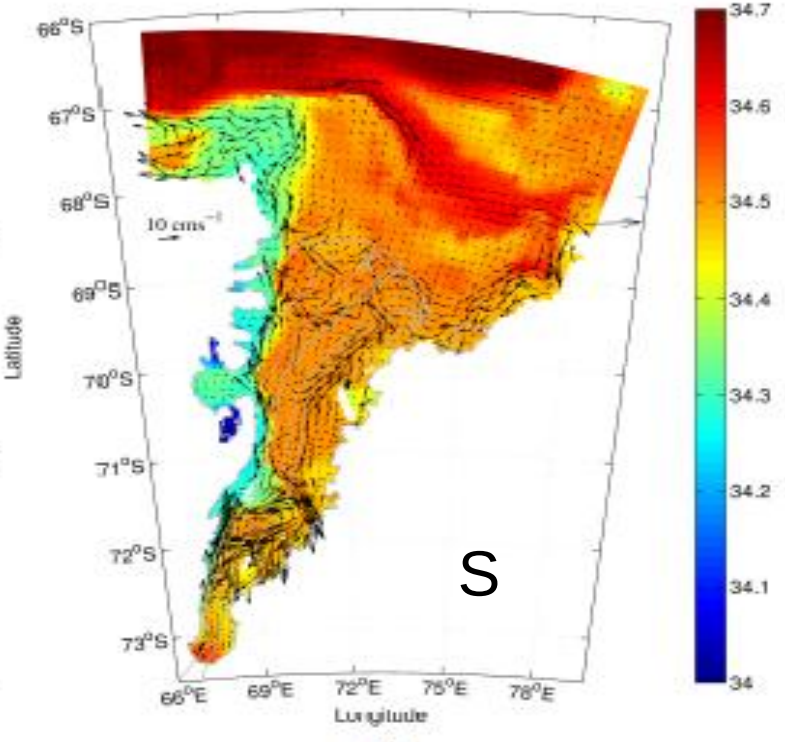
Upper

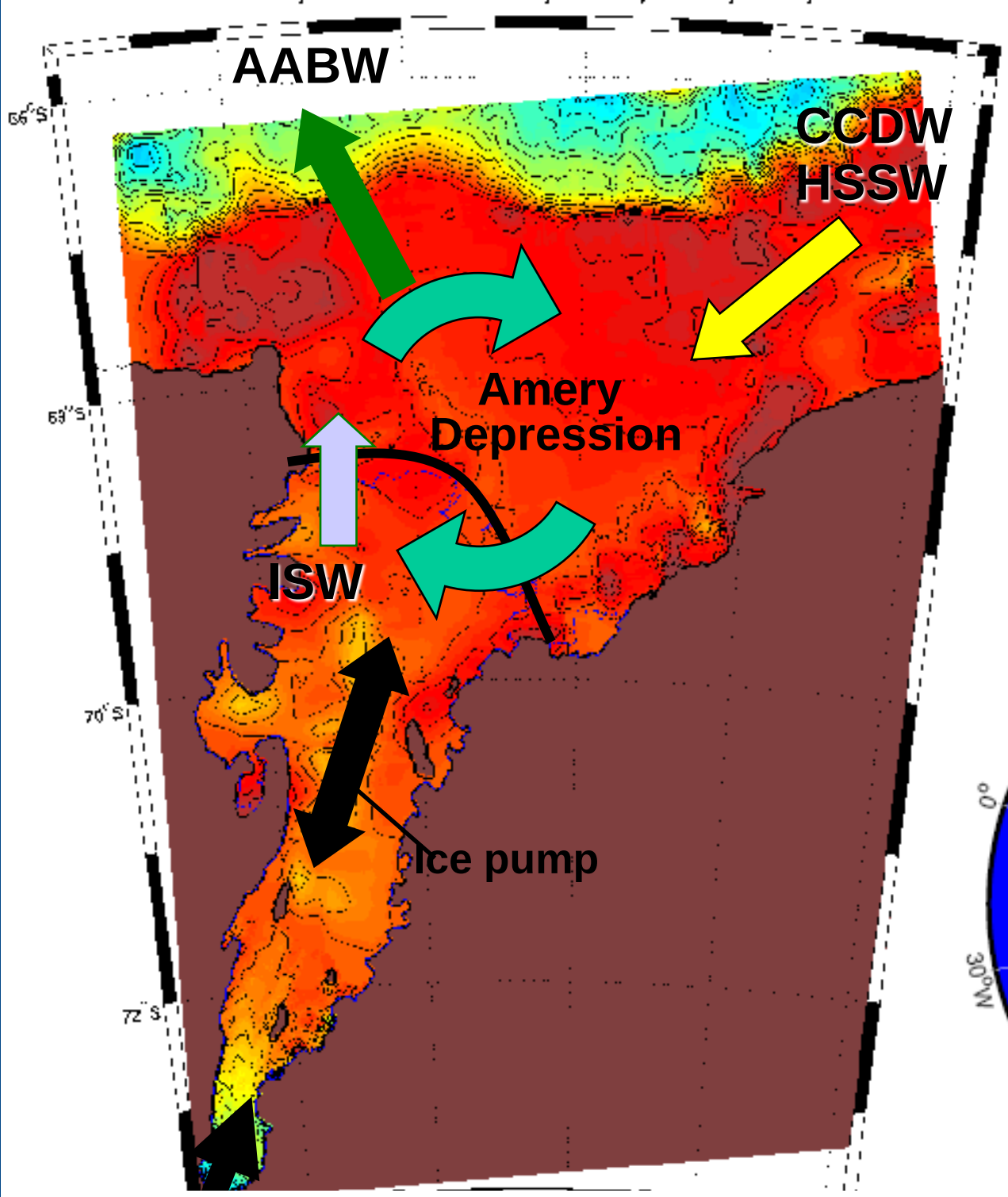

θ
Latitude
Longitude
(a)


S
Latitude
Longitude
(b)

Lower


θ
Latitude
Longitude
(c)

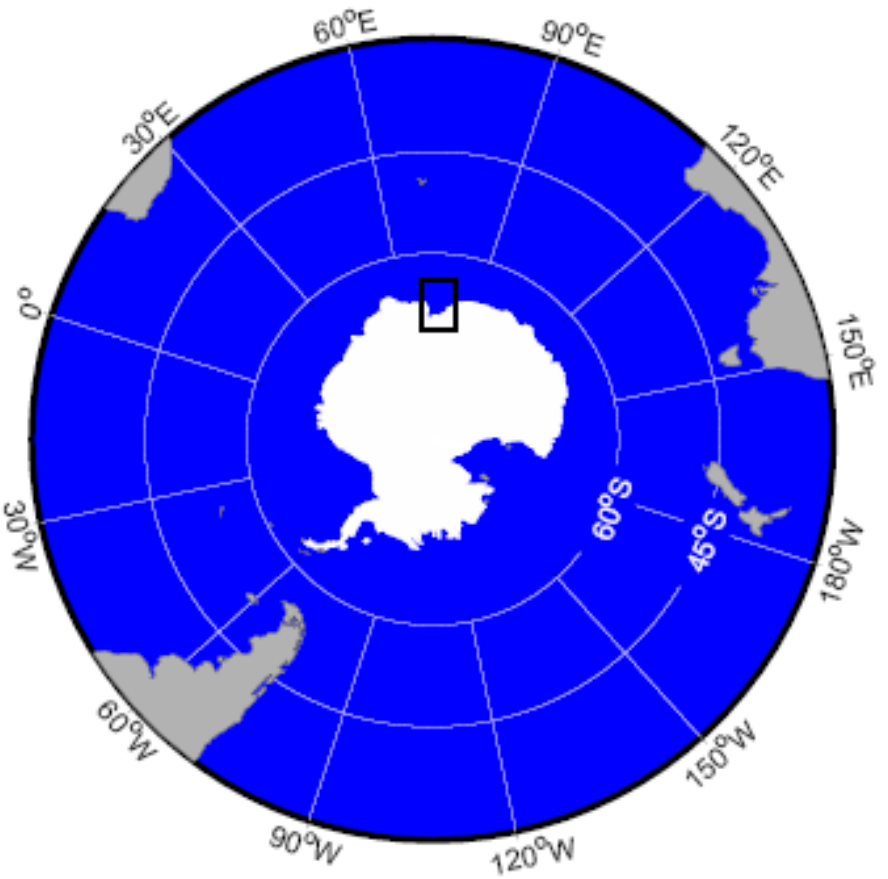

S
Latitude
Longitude
(d)



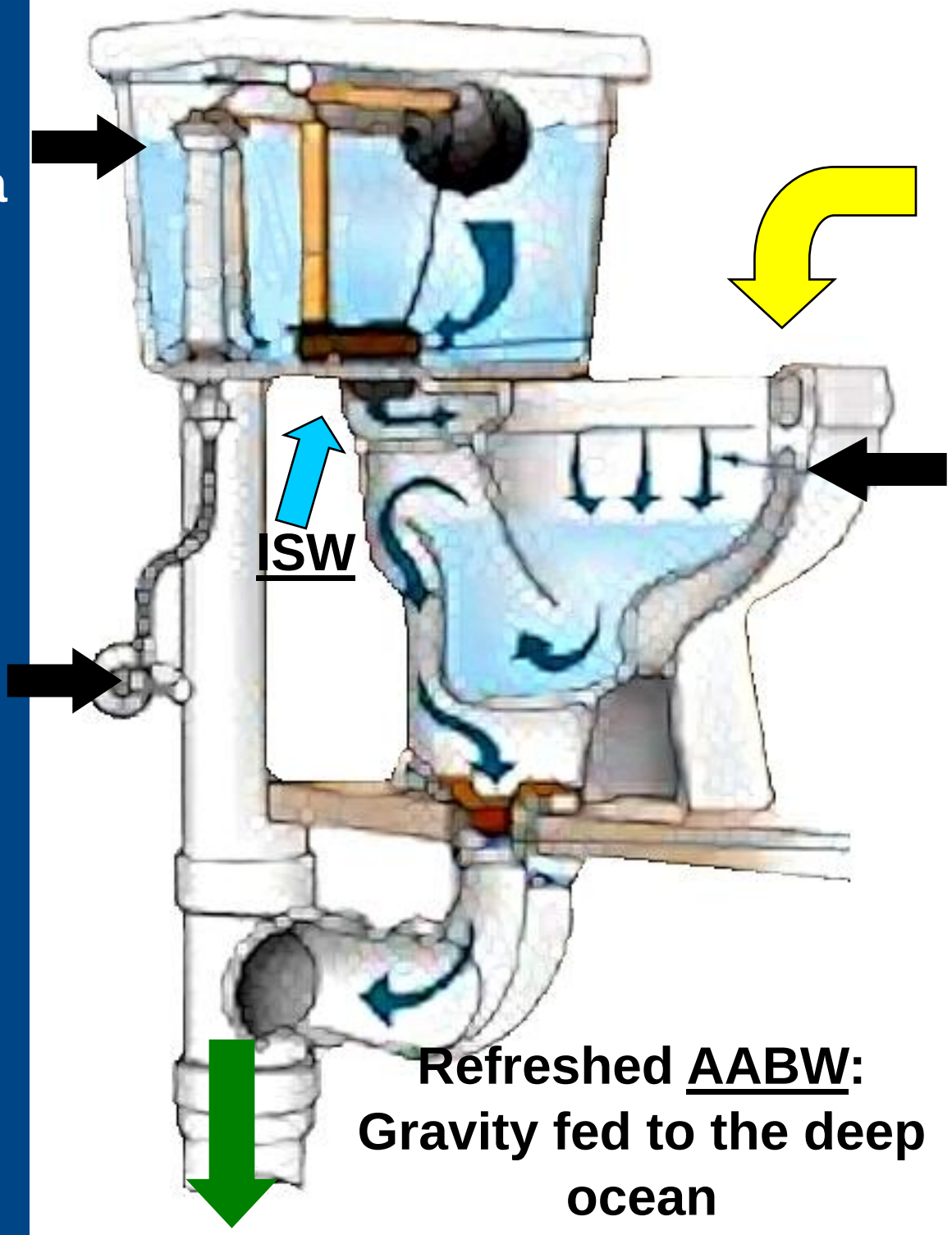
Lambert/Mellor/Fisher glaciers

General summer circulation of the Prydz Bay and Amery Ice Shelf region.

(Smith 1984; Wong 1994; Hongxia 2005)



Ice Sheet Antarctica



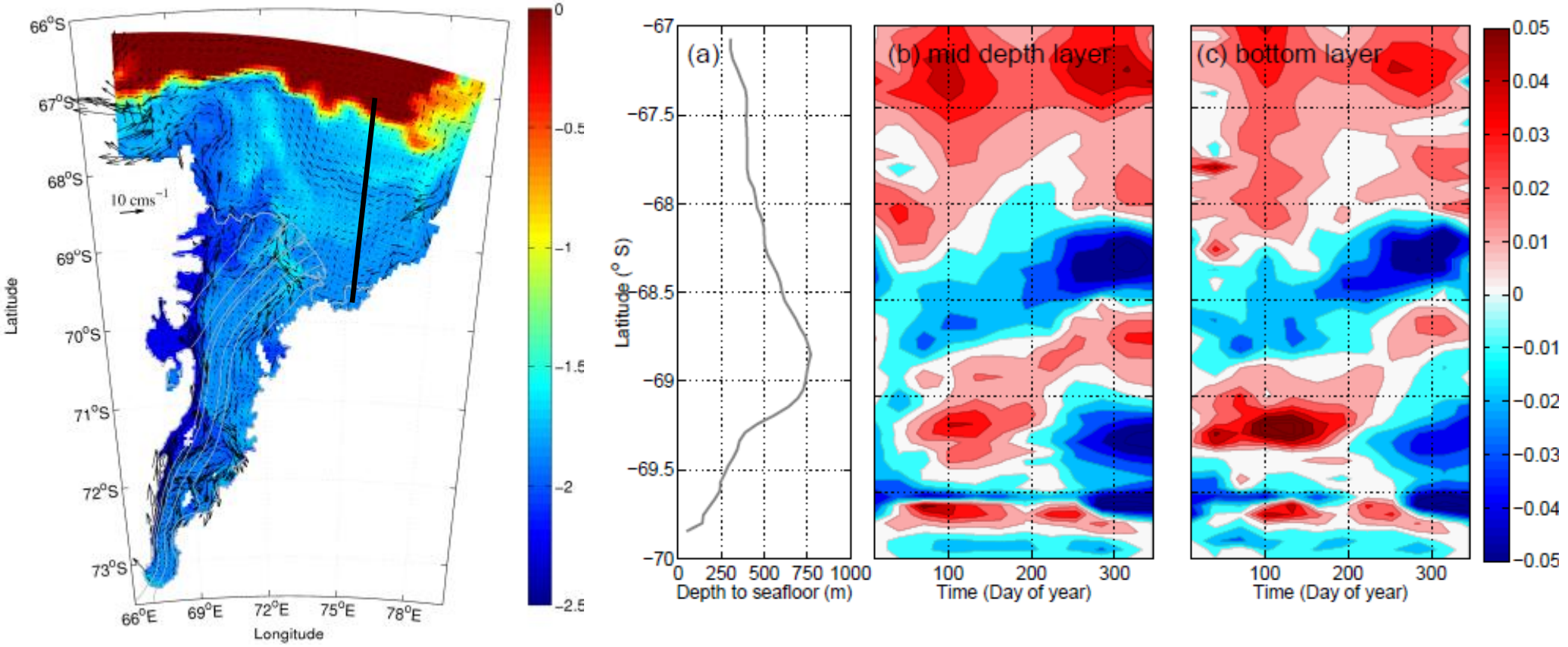
CCDW and HSSW

Continental Shelf seas (e.g. Prydz bay)

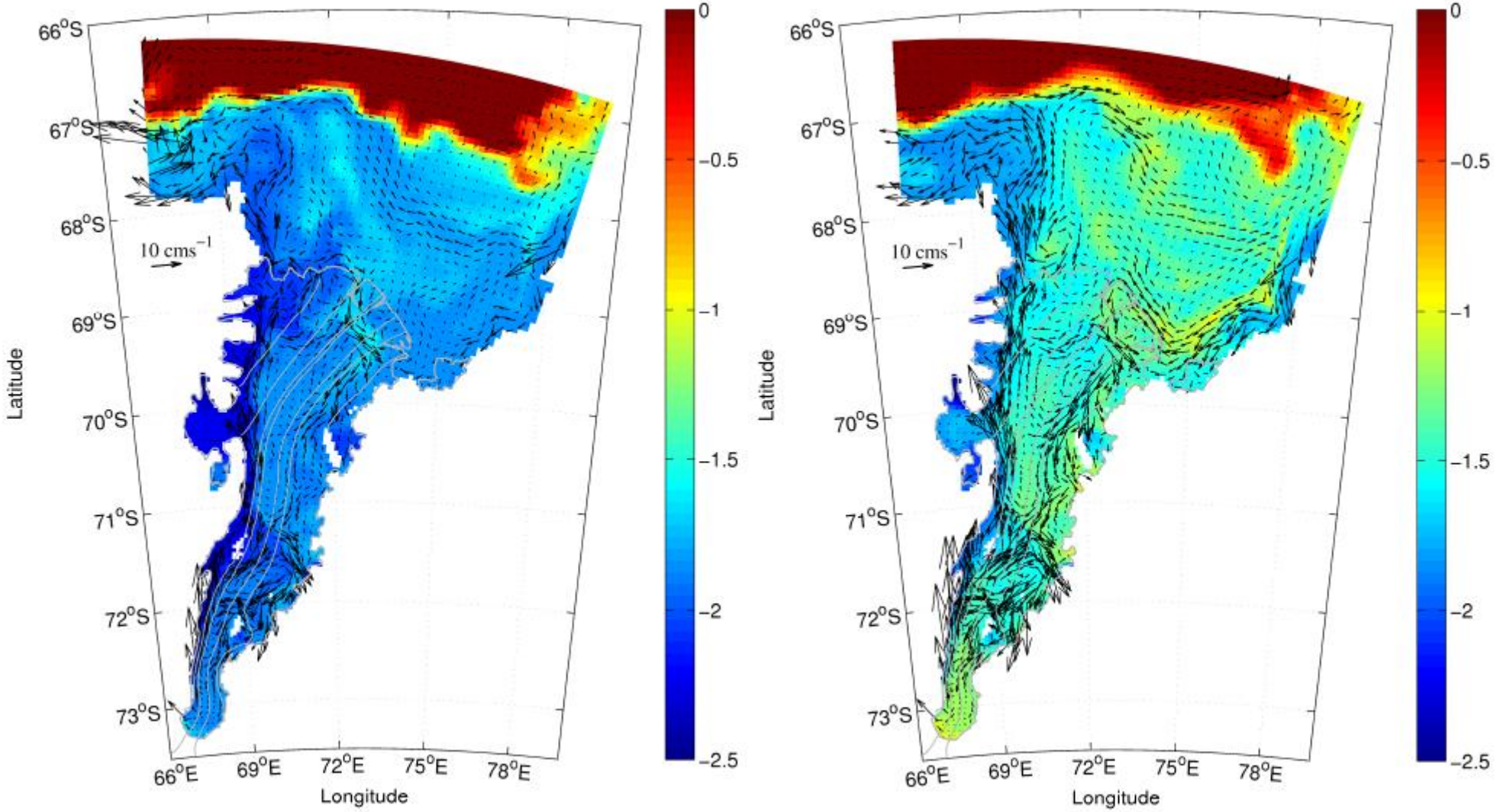
Inflowing Glaciers

Not quite right...

Winter Circulation

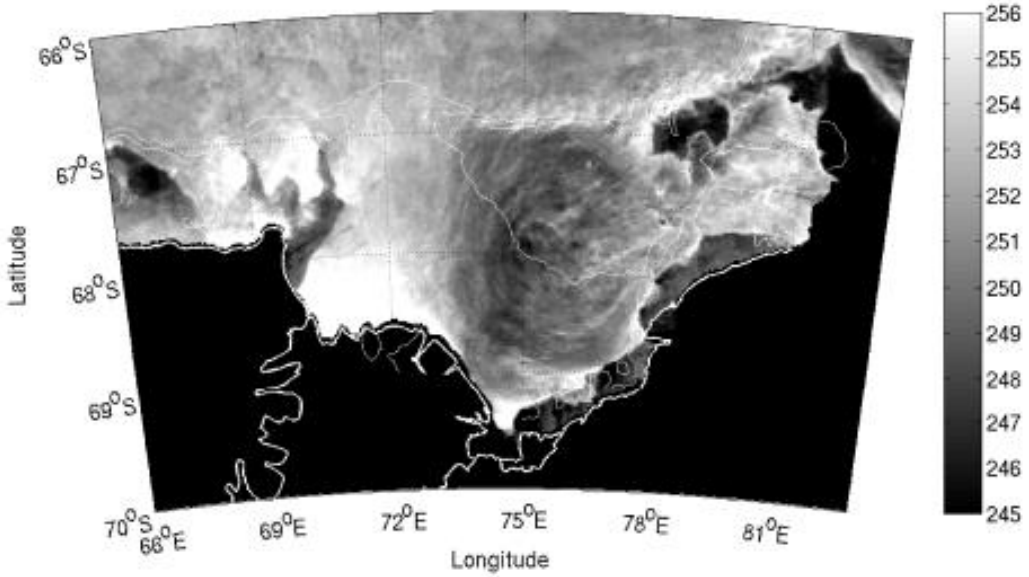


Polynyas control circulation and melt/freeze

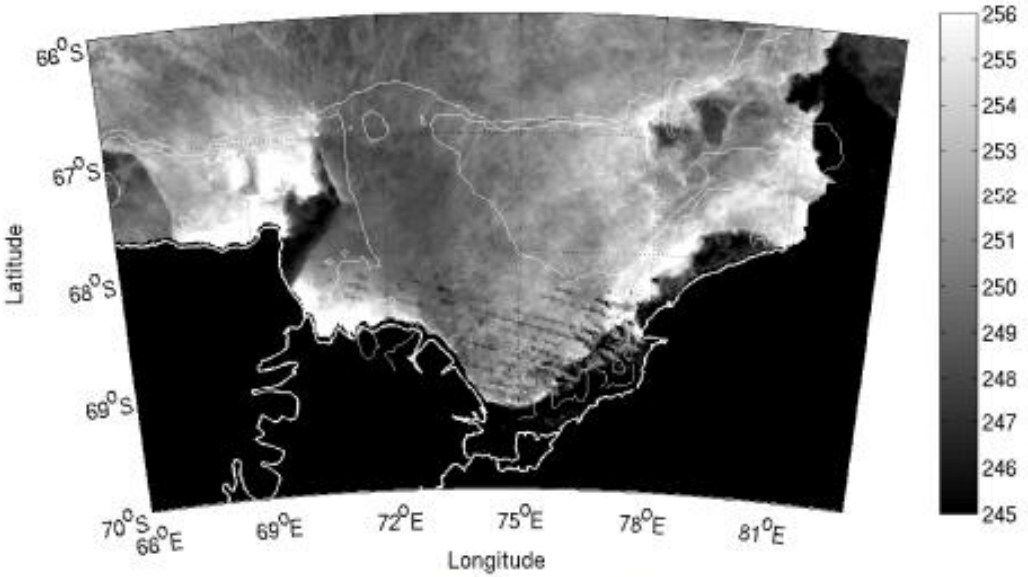


(a) Reference simulation

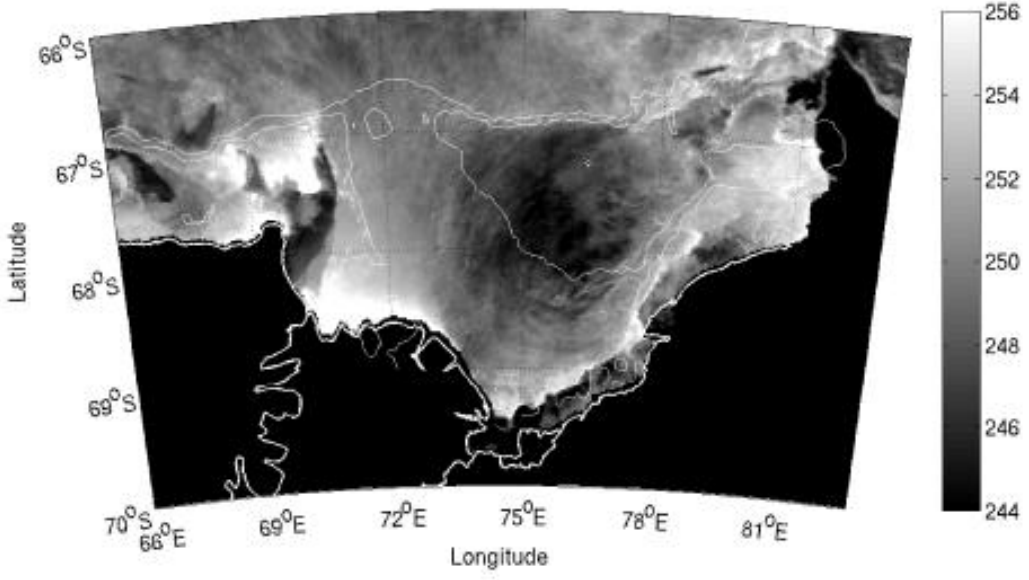
(b) Reference without Barrier polynya



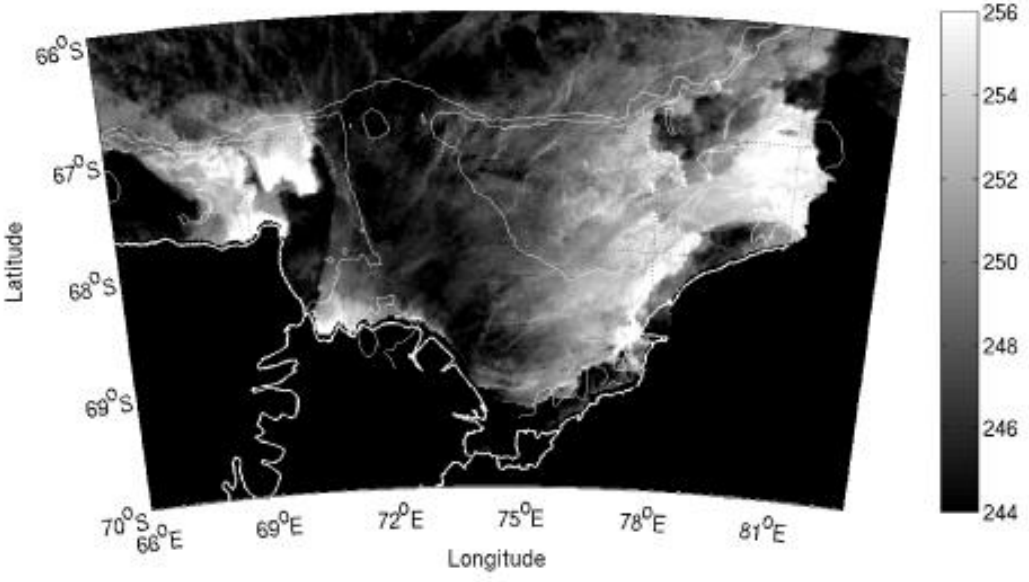
(a) 2005 DOY 121-140



(b) 2005 DOY 181-200



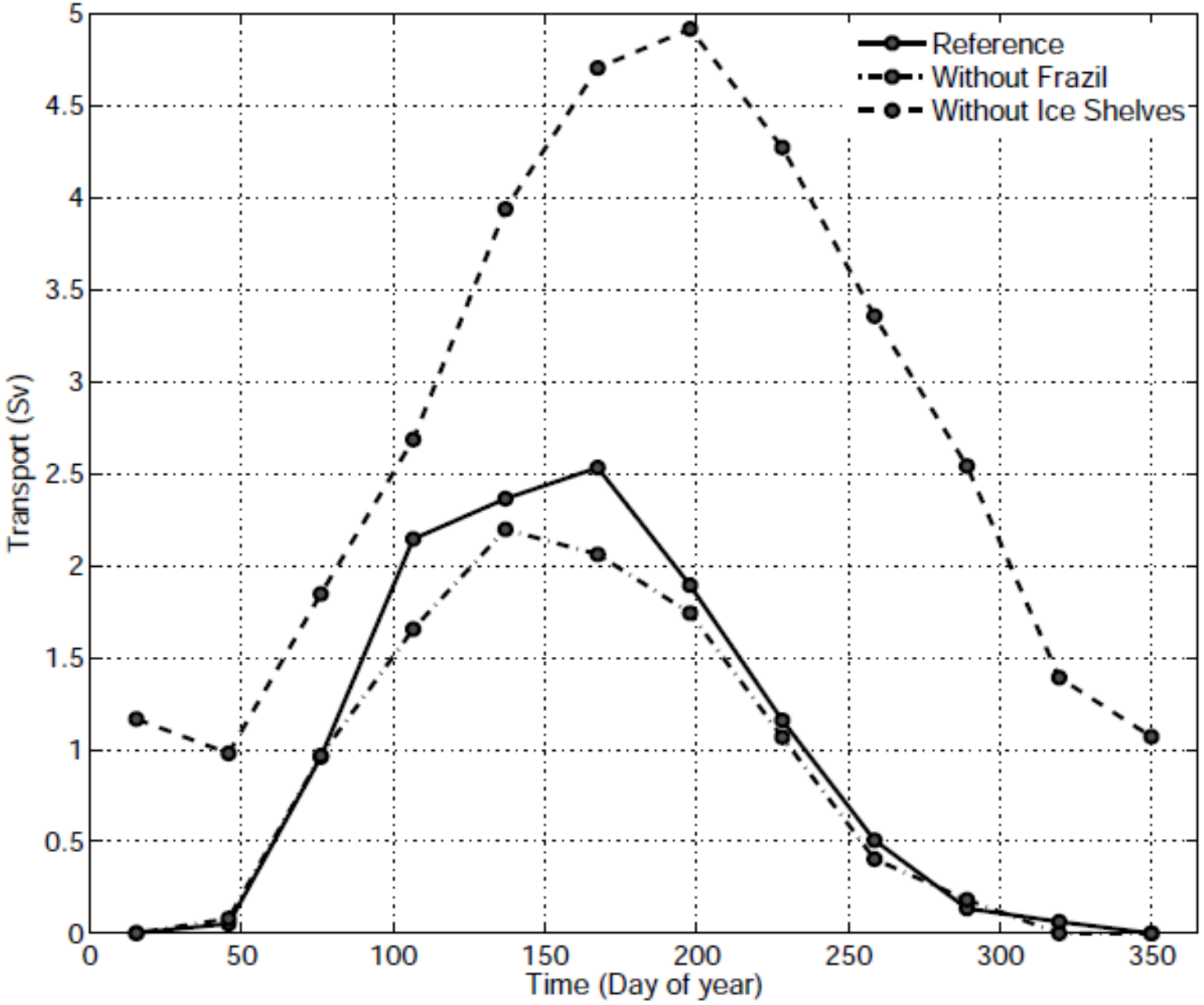
(c) 2006 DOY 121-140

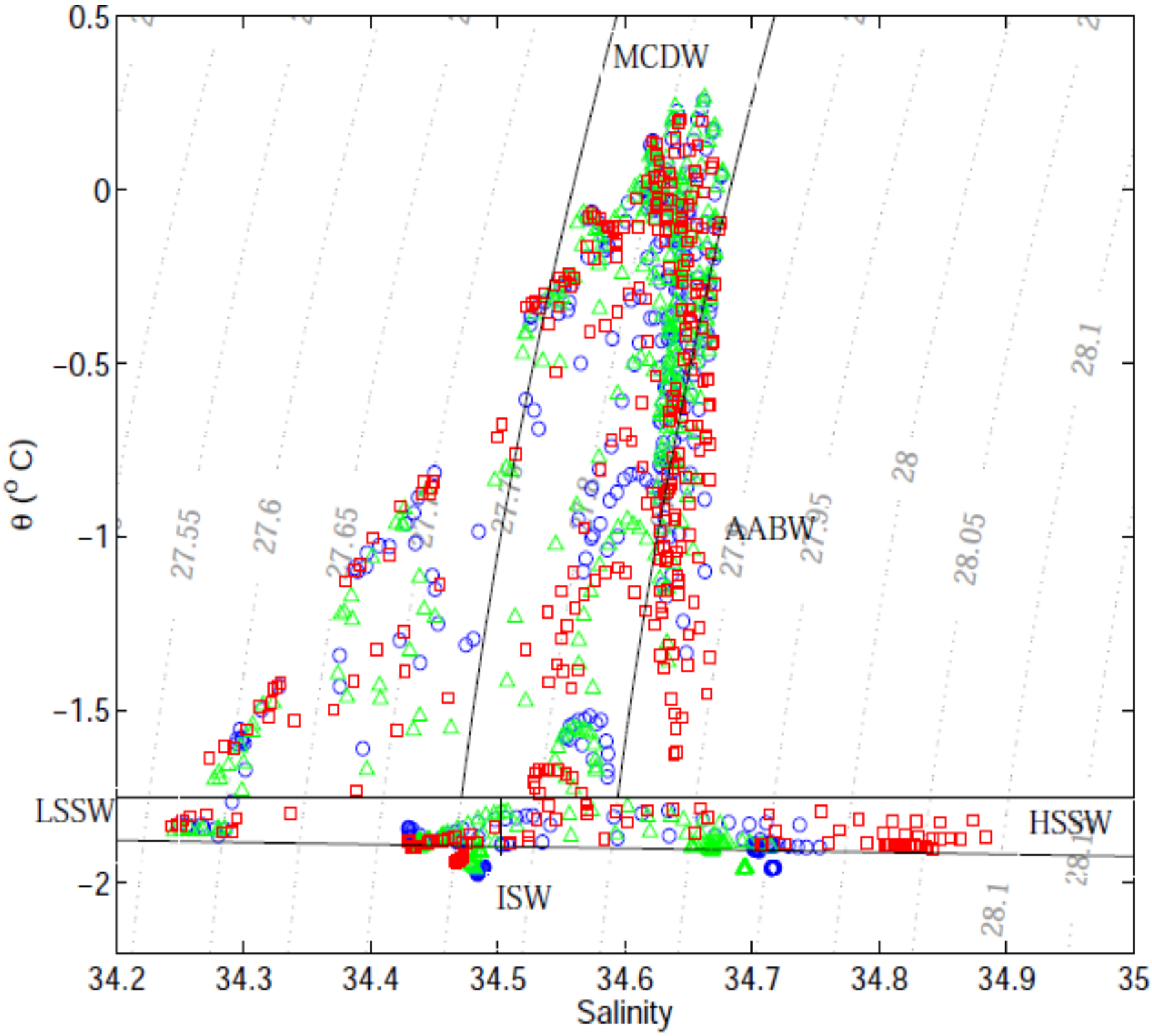


(d) 2006 DOY 181-200

20 day composite thermal infrared MODIS images (Fraser et al. 2009)

Sensitivity of AABW to melt water




MCDW
AABW
LSSW
ISW
HSSW
θ (°C)
Salinity
0.5
0
−0.5
−1
−1.5
−2
34.2
34.3
34.4
34.5
34.6
34.7
34.8
34.9
35
27.55
27.6
27.65
27.7
27.75
27.8
27.85
27.9
27.95
28
28.05
28.1

Response to Climate Change

Air-Sea flux change (%)	Lateral warming (°C)			
	0	0.25	0.5	1
0	R	L1	L2	L3
-10	A1	+0.5		
-20	A2		+1	
-40	A3			+2

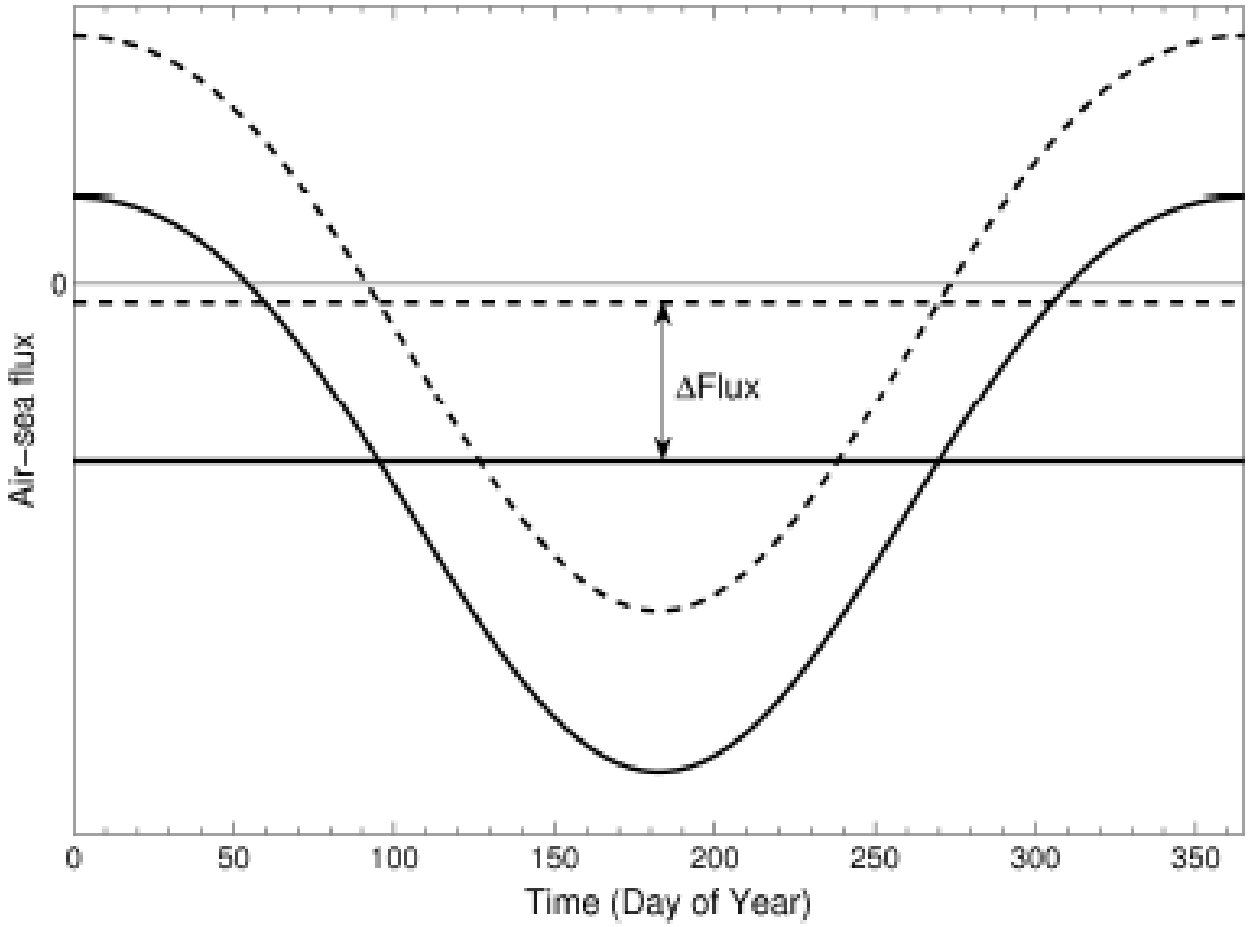
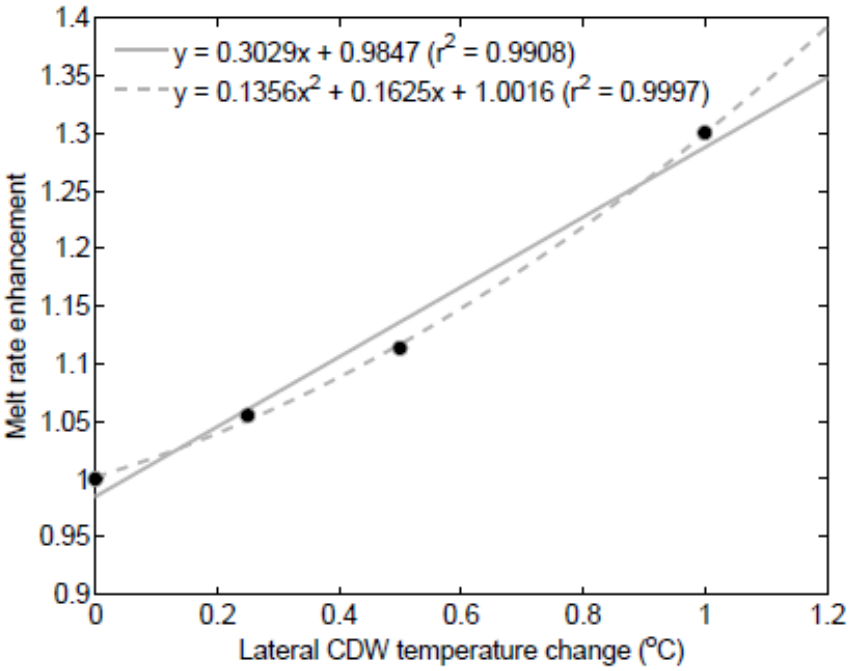
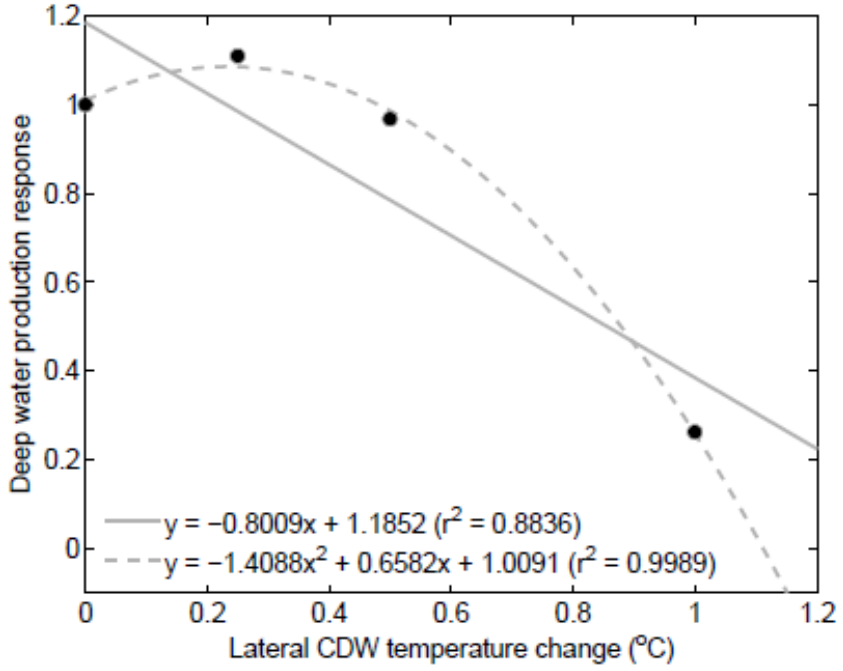


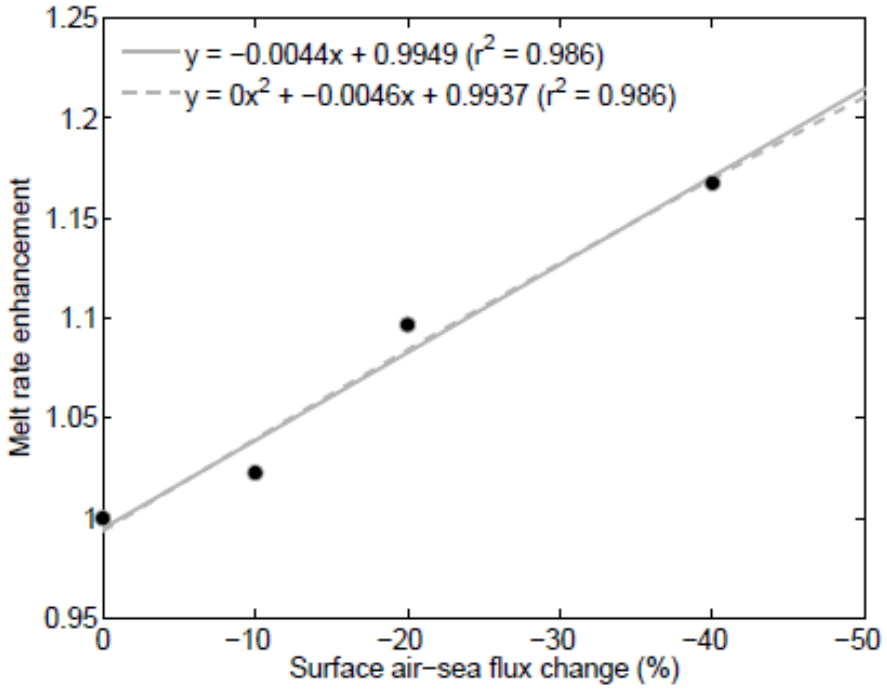
Figure 7.1: Idealised seasonal cycles of either heat and/or freshwater air-sea fluxes in the Southern Hemisphere. The change in surface air-sea fluxes (Δ Flux) is applied to the annual mean. The mean is calculated separately for each grid cell

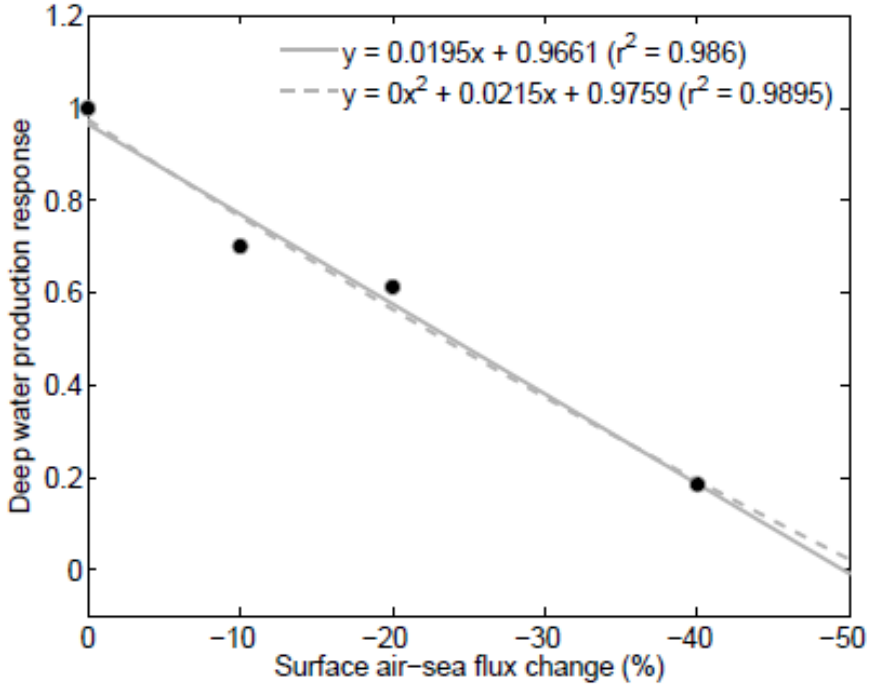

y = 0.3029x + 0.9847 (r^2 = 0.9908)
y = 0.1356x^2 + 0.1625x + 1.0016 (r^2 = 0.9997)
Melt rate enhancement
Lateral CDW temperature change (°C)
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
0
0.2
0.4
0.6
0.8
1
1.2

(a)

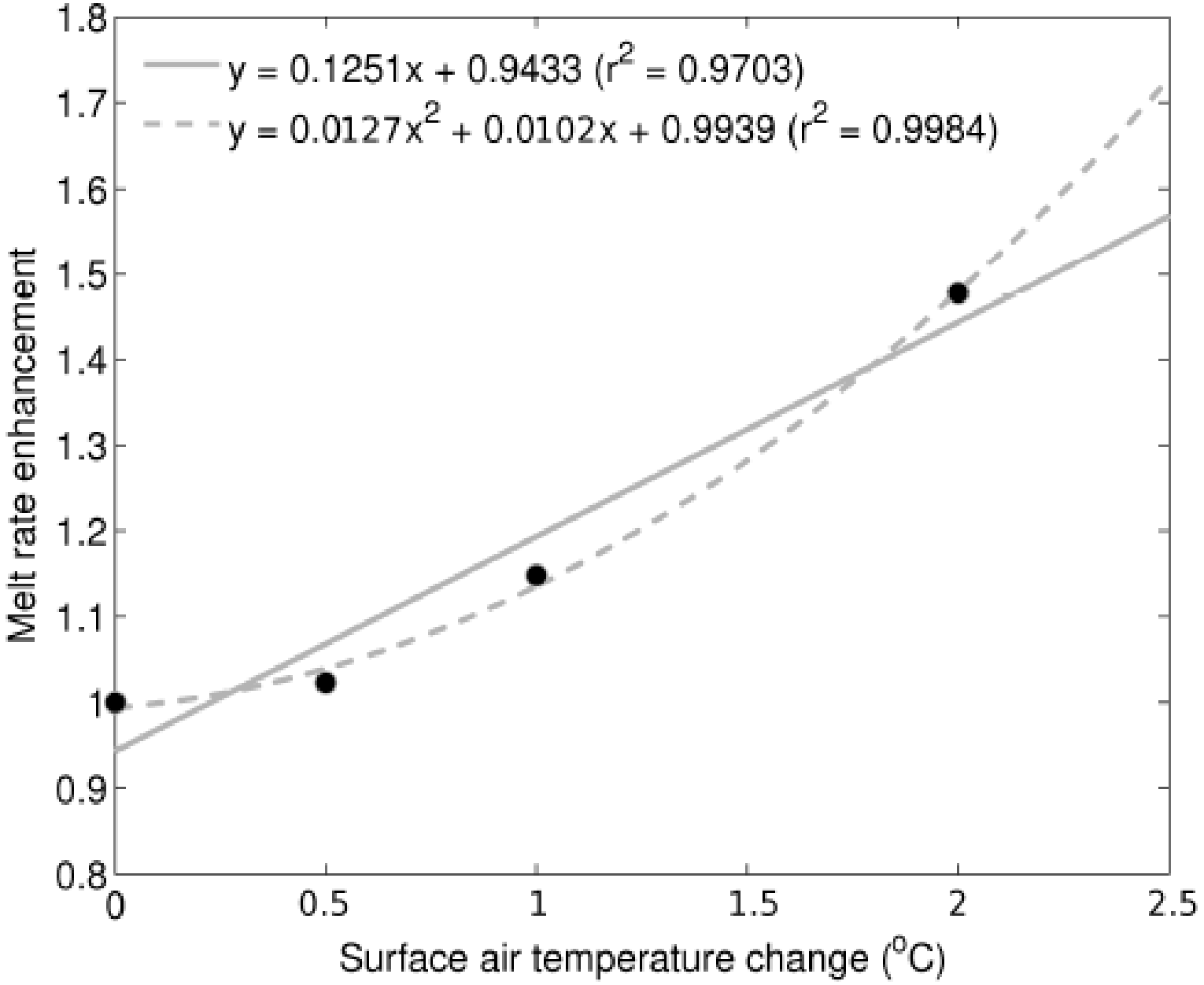

y = −0.8009x + 1.1852 (r^2 = 0.8836)
y = −1.4088x^2 + 0.6582x + 1.0091 (r^2 = 0.9989)
Deep water production response
Lateral CDW temperature change (°C)
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2

(b)

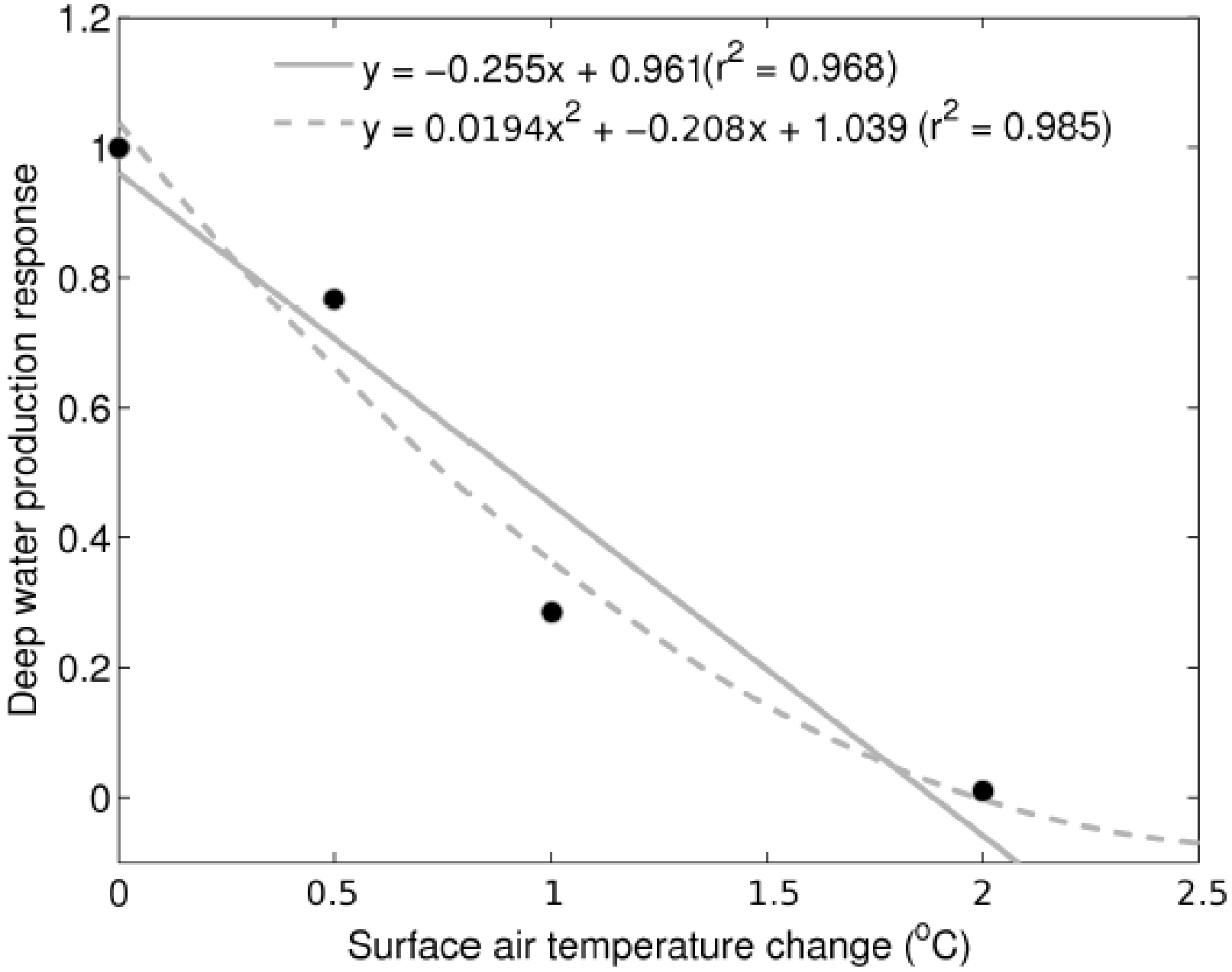

y = −0.0044x + 0.9949 (r2 = 0.986)
y = 0x2 + −0.0046x + 0.9937 (r2 = 0.986)
Melt rate enhancement
1.25
1.2
1.15
1.1
1.05
1
0.95
0
−10
−20
−30
−40
−50
Surface air−sea flux change (%)

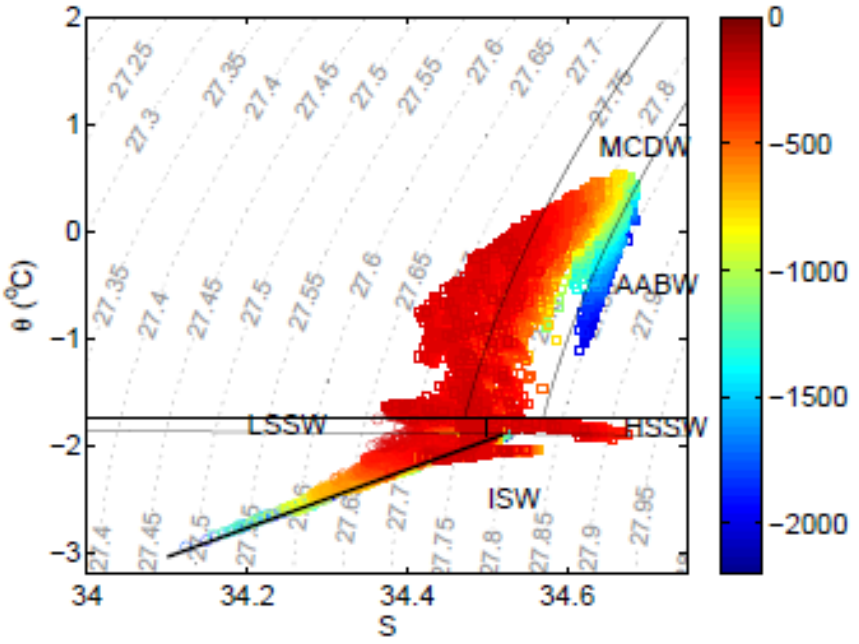

y = 0.0195x + 0.9661 (r2 = 0.986)
y = 0x2 + 0.0215x + 0.9759 (r2 = 0.9895)
Deep water production response
1.2
1
0.8
0.6
0.4
0.2
0
0
−10
−20
−30
−40
−50
Surface air−sea flux change (%)

Enhanced basal melting of ice sheets

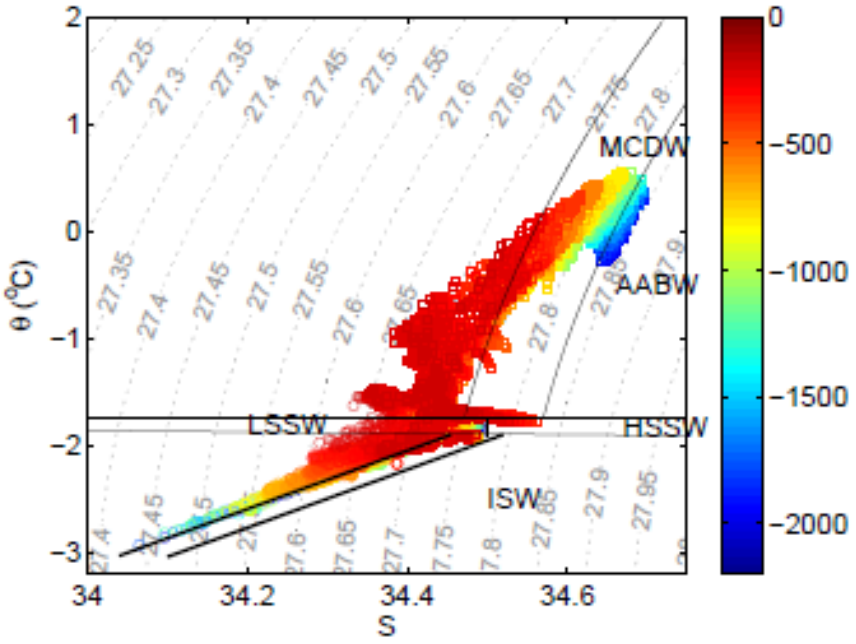


Shutdown of AABW at +2ºC

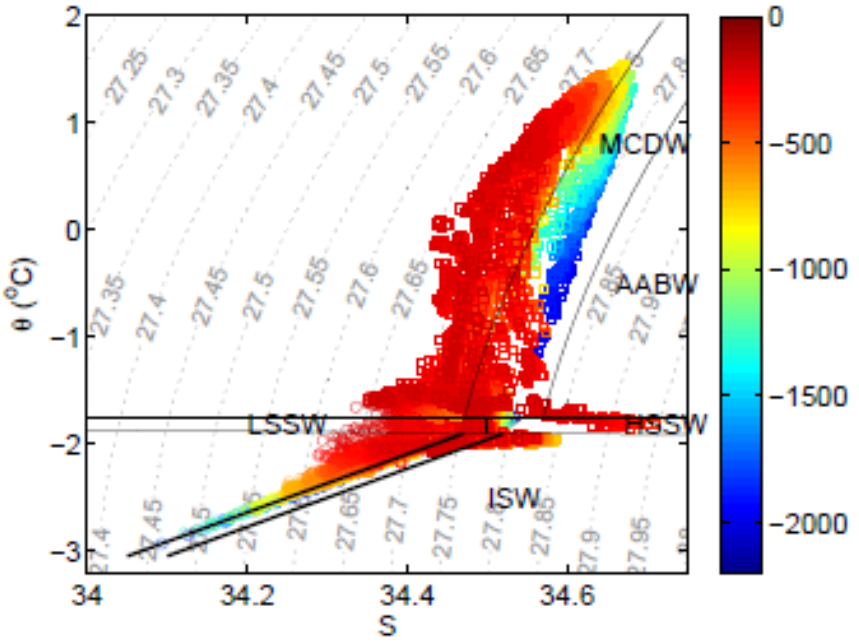




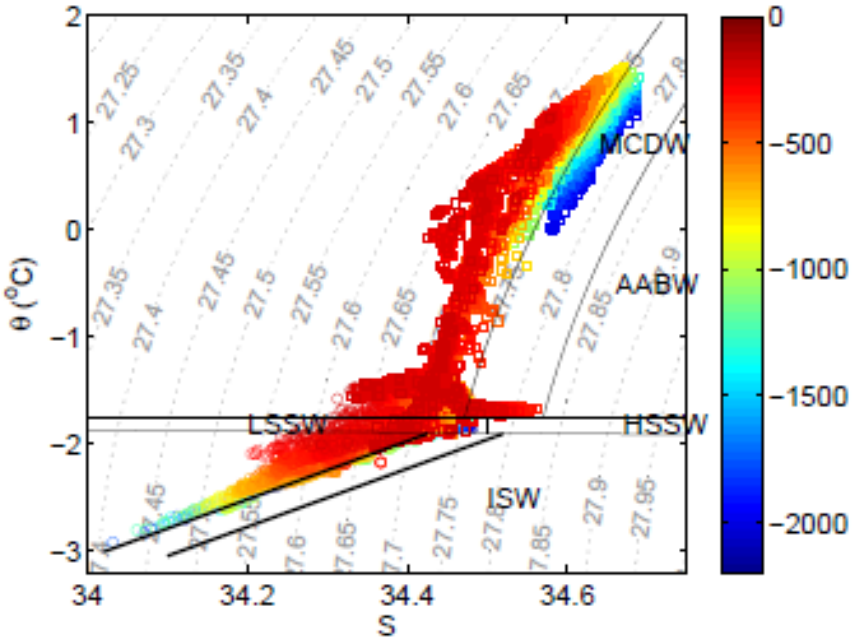
(a) Reference



(b) Air-sea: -40 %



(c) Lateral warming: 1 °C



(d) Combined: +2 °C

Concluding remarks

- Frazil ice enhances marine ice accretion and limits supercooling with implications for ice shelf mass balance and dense water formation
- Freshwater from melting ice shelves inhibits AABW formation by 2.8 times.
- A warming of +1 can potentially remove the Amery Ice Shelf in 500 years
- AABW production will shutdown with a combined 40 % reduction in polynyas and a 1^{o}C warming of CDW

Concluding remarks

- With respect to modelling Antarctic coastal oceans, subgridscale icebergs influence AABW formation and melting of ice shelves.
- Parameterisation in ECCO2?
- Global models (such as ECCO) without dynamic frazil models should at least limit the supercooling due to ice-shelf/ocean interaction
- Remove in 1 timestep?
- Regional models can provide fluxes for global models

THE DAY AFTER TOMORROW
WHERE WILL YOU BE?
IN THEATERS WORLDWIDE MAY 28, 2004

Comunity Ice-Shelf Ocean Model

Goal: Develop a fully coupled ice-sheet/ocean model to investigate links between climate change, ice-shelf melting and bottom-water formation and sea level rise.

Some potential collaborators:

Ben Galton-Fenzi, John Hunter, Nathan Bindoff, Frank Colberg, Roland Warner (UTas, ACE CRC, Tasmania)

Mike Dinniman and John Klinck (ODU, Virginia)

Simon Marsland, Siobhan O'Farrell (CSIRO, Australia)

Rachael Mueller, Laurie Padman, Susan Howard (ESR, U.S.A)

Robin Robertson (ADFA, Australia)

Andrea Bergamasco, Ariana Trevisiol, Sandro Carniel (OGS, Italy)

Mike Williams, Natalie Robinson (NIWA, New Zealand)

Lars Smedsrud (Bjerknes Centre for Climate Research, Norway)

Daniel Feltham (CPOM, U.K.)

Community Ice Shelf Ocean Model

- Already dedicated support from:
  - Australian Research Collaboration Service provides support and maintenance http://www.arcs.org.au.
  - Both National and Tasmanian Partnership for Advanced Computing
  - Old Dominion University, Norfolk, US
  - Earth and Space Research, Seattle, US
  - Southern Ocean Physical Oceanography and Cryosphere Linkages (SOPHOCLES)
- What about sea-ice? A much bigger list of users!

CIOMP - Mozilla Firefox

File Edit View History Bookmarks Tools Help

arcs.org.au https://projects.arcs.org.au/trac/ciomp

Google

CIOMP

Search

Login | Preferences | Help/Guide | About Trac | Register | OpenID Login

Wiki | Timeline | Roadmap | Browse Source | View Tickets | Search

Start Page | Index | History | Last Change

Community Ice Ocean Modelling Project

Useful Markups

Markup	Display	Markup	Display
(C)	©	(R)	®
(TM)	™	(c)	©
+/-	±	--	—
->	→	...	…
/\	^	1/2	½
1/4	¼	3/4	¾
<-	←	<->	↔

Done

seaice - Mozilla Firefox
File Edit View History Bookmarks Tools Help
myroms.org https://www.myroms.org/projects/seaice/wiki
Most Visited Getting Started Latest Headlines UTas Webmail - Log In
ROMS > Authorized
seaice

Welcome to ROMS/TOMS Distribution

The goal of this web-based interface is to manage ROMS/TOMS Framework distribution, bug fixes, updates and enhancements.

License and Disclaimer

ROMS/TOMS Framework is copyright (c) 2002-2008 by The ROMS/TOMS Group. Please read the license text. Any contributions to this website (code or documentation) confer membership in The ROMS/TOMS Group and indicate that you agree with the terms of the license.

Getting Started

- Register as a ROMS/TOMS User
- Change your password
- Download, modify, and update the ROMS/TOMS source code using SVN
- Report bugs, propose enhancements and track tasks using Trac
- Check the ROMS/TOMS developers blog for detailed algorithms updates
- Visit wikiROMS for web-based user and technical reference
- Discuss issues, make announcements, request help using the ROMS/TOMS Forum
- View all Trac tickets

Download in other formats:

Plain Text

Done